ORIGINAL PAPER

Investigation of slope movements and landslide susceptibility analysis of Karabük-Yenice area in NW of Turkey

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Abstract
Slope movements are commonly occurring natural disasters damaging the infrastructures, upper structures, and nature. Among the slope movements, landslide is the most damaging and frequent natural disaster. This study investigates the previously occurring slope instability and runs a landslide susceptibility analysis for the Karabük-Yenice area in NW of Turkey. Types of slope movements in the area were mainly slide, flow, and fall type failures. The most frequent slope movements were slides and flows. Fall type of movement, however, was seen only in two locations in bedrock as rock falls. After the determination of the mass movements, landslide susceptibility analysis was performed for the study area. Four predisposing parameters, geology, slope, aspect, and distance to the river were used in the frequency ratio landslide susceptibility analysis. Geographical information system (GIS) and frequency ratio methods were used in landslide susceptibility analysis. GIS made it easy to prepare the required layers and to perform analysis for generating a landslide susceptibility map. The outcome of this study, the landslide susceptibility map, reveals the susceptibility in five classes, namely, very low, low, moderate, high, and very high. The locations of the previous landslides defined by the fieldwork were overlaid on the landslide susceptibility map to verify the validity of the susceptibility analysis and make evaluations and interpretations.

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Introduction

Slope instability processes are the product of local geomorphic, hydrologic, and geologic conditions; the modification of these conditions is by geodynamic processes, vegetation, land-use practices and human activities, and the frequency and intensity of precipitation and seismicity (Soeters and Van Westen 1996). This study focuses on the slope instability occurring within the study area of Yenice county of Karabük, a densely populated settlement under the influence of west Black Sea climate conditions. The study area has a high potential for landslides since geologic and topographic features provide suitable conditions for developing landslide type mass movements. The Karabük-Yenice settlement area has experienced several natural disasters such as flooding, landslides for several decades. Almost all the dwellings in the Yenice settlement area and its villages were evacuated in accordance with the Turkish law no 7269 to the safer locations due to mainly landslides occurred in the region in 1985. New development sites were preferred near the Yenice city center because landslide hazard still existed in the areas of evacuated villages. In terms of mass movements, 61 areas with landslides were

determined in the study area, while mass movements of rockfall type were observed only in two villages, located in a forested area outside the city limits and along a highway.

Several studies have generated landslide susceptibility maps by applying different methods. Yalcın et al. (2011) used the frequency ratio, analytic hierarchy process, two-variable statistics, and logistic regression methods to produce a landslide susceptibility map in Trabzon NE of Turkey. Ozdemir and Altural (2013) stated that the frequency ratio method for determining landslide susceptibility is the most prominent method, besides the weighted average and regression methods undertaken for Sultan Mountains the extension of west Taurus Mountains in the Mediterranean Region. Kumtepe et al. (2011) developed a landslide susceptibility map using geology, slope, aspect, proximity to fault, proximity to river, and land cover data sets in the southwest of Sinop located in the mid part of the Black Sea Region. Erener and Lacasse (2007) used elevation, geology, slope, distance to the river, aspect, and climate parameters in producing landslide susceptibility maps using frequency ratio and logistic regression methods in the southeast of Norway and compared the defined landslide areas in the susceptibility map with previously occurred landslides to test the accuracy of their study. Pradhan and Lee (2010b) used the frequency ratio method with slope, geology, aspect, proximity to river, and land use parameters in defining landslide susceptibility in the Penang Island of Malaysia. Dag and Bulut (2012) used the frequency ratio method on lithology, weathering, slope, aspect, land cover, elevation, and distance to river parameters for Rize Cayeli in preparation of the GIS landslide susceptibility map. Silalahi et al. (2019) have performed a landslide susceptibility analysis using the frequency ratio model and GIS mapping to assess the contribution of conditioning factors to landslides in Bogor, West Java, Indonesia. Khan et al. (2019) have assessed the landslide susceptibility using the frequency ratio method for northern Pakistan and revealed that significant parameters on the spatial distribution of landslides are distance to road and slope gradient followed by geology. Sevgen et al. (2019) have made a new performance assessment in the sensitivity analysis of landslides of the Kaleköy Dam (Turkey) by using neural networks and logistic regression with photogrammetric techniques.

Some landslide investigation studies were performed nearby Yenice and the western Black Sea Region. A previous similar study of landslide susceptibility zoning for the north of the Yenice area was conducted using multivariate statistical techniques by Ercanoglu et al. (2004). Another previous similar study in the region belongs to Ercanoglu (2005) who performed landslide susceptibility assessment in the western Black Sea Region of SE Bartin by using an artificial neural network method. Can (2014) has indicated the importance of meteorological, geological, and geodetic measurements for monitoring

landslide-prone areas along the Zonguldak-Eregli highway. In the same area, Ercanoglu et al. (2016) have conducted a landslide susceptibility study with the Chebyshev theorem. Can et al. (2019) have produced a landslide susceptibility map and prepared a landslide database using artificial neural networks in Ovacık, another district of Karabük. In the Western Black Sea Region, which includes the study area, there are landslide susceptibility studies conducted using various methods by Ercanoglu et al. (2008), Ercanoglu and Temiz (2011), Yilmaz et al. (2012), Alkevli and Ercanoglu (2011), and Hasekiogullari and Ercanoglu (2012).

The main objective of this study is to investigate the slope failures and run a landslide susceptibility analysis by using GIS for the Yenice area. Field studies for recording slope failures and GIS procedures for data handling, updating, and analyses were undertaken in this study. As a result, a slope failure inventory map and a landslide susceptibility map were produced. Results of the study were promising in terms of defining landslide type slope movements and identifying areas prone to landsliding. The results of this study can be used by local municipalities or government agencies for settlement, hazard zonation, and mitigation. Also, this study, which is one of the first studies analyzing landslide potential of the Yenice area by using GIS, can be a reference study for future studies on similar subjects.

General features of the study area

The study area is located in and around the county of Yenice within the borders of Karabük province in NW of Turkey and encompasses the central districts of Yenice and surrounding villages such as Bagbası, Guney, Hisar, Ibricak, Kale, Kayaarkasi, Kayadibi, Oren, Tir, Yamac, Yenikoy, Derebası, Celtic, Yesilkoy, and Yazikoy. The location and boundaries of the study area are shown in Fig. 1. Morphologically, the topography of Yenice covering a total area of 1150 km^2 depicts typical main features of the west Black Sea Region terrain; in other words, flat terrain and plain type morphology are of a rarity in the region (Guner 1975). As a result of the rugged and inclined terrain, there are limited areas for agriculture and cultivation. Yenice River and its tributaries flow through the middle of the study area. Several creeks, however, discharge into Filyos River, such as Acısu, İncecay, Büyükdere, Şimşir, and Kirazpinar creeks. Yenice has fertile forest lands covering large areas. Yenice is settled in an elevation of 112 m above sea level and the highest point is the Kecikiran Hill in the morphology around Yenice. The total population of Yenice is 22,156 (Provincial Directory of Environment and Urbanization 2012). The mean annual precipitation and mean annual relative humidity in the Yenice area are defined as 1200 mm and 76.2% respectively. The mean annual temperature is measured at 13 °C with an

Fig. 1 Location of the study area (URL-1 2020; Karabuk Provincial Special Administration 2020)
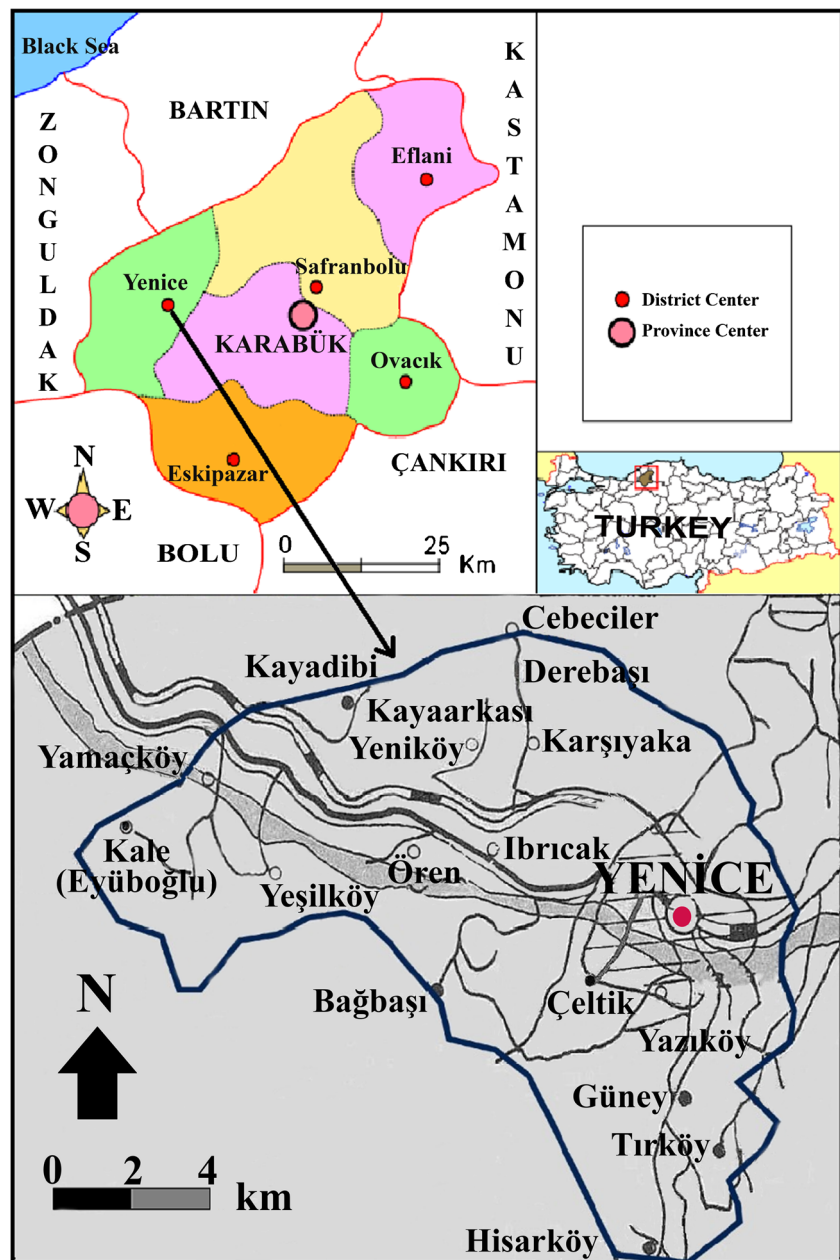
average of 30 °C in summers and 1 °C in winters. A typical Black Sea climate prevails in Yenice with mild and occasional rain shower in summers. The winters go by a little bit harsh and snowy in Yenice due to its inland location. Yenice gets approximately 25 days of snowfall each year. The most precipitation in Yenice occurs in the spring months (Provincial Directory of Environment and Urbanization 2012).

Geological setting

The study area is located in the west Black Sea Region in NW Turkey. Ketin (1966) defined the region as Pontide, one of the

main tectonic assemblages consisting of basement metamorphic rocks, a plutonic body, and various sedimentary rocks (Alan and Aksay 2002). From Upper Cretaceous to the end of the Mid-Eocene, there was a compressional tectonic regime due to the Neotethys Ocean closure by subduction generating island-arc products in the region. Folds with NE-SW directions developed rather than large thrusts in the region due to the compressional regime. Also, strike-slip faults related to the North Anatolian Fault System (NAFS) exist in the south of the study area (Yigittepe 2013). Nine geological formations and units are seen in the study area, such as Bolu Granitoid (Peb), Ulus formation (Ku), Yemişlicay formation (Ky), Akveren formation (KTa), Yığılca formation (Ty), Caycuma formation

(Tc), talus (Qym), and alluvium (Qal). Distributions and contacts of the geological formations and units are shown in Fig. 2. Bolu granitoid unit named by Erendil et al. (1991) contains granodiorite, tonalite, granite, gabbro plutonic rocks, and lamprophyre and aplite dykes (Alan and Aksay 2002). The plutons with emplacement depths varying from 2 to 5 km composed of tonalite, granodiorite, and granite with granophyric textures indicating shallow depth crystallization. The Ulus formation (Ku) named by Akyol et al. (1974) consists of turbidite deposits and olistoliths. The formation mainly contains grayish-green, gray and black sandstone, shale, marl, limestone and conglomerate intercalated sandy limestone with olistolith blocks of metamorphics, volcanics, granite, marble, and mainly limestone. Also, the Ulus formation has two members: (1) Ahmetusta member (Kua) consisting of conglomerates and (2) Sunduk member (Kus) consisting of limestones in the region. The fieldwork verified that the Ulus formation consists of mainly flysch type material in the study area. Also, according to a study by Ercanoglu et al. (2016) and MTA maps, reports, and fieldwork, it was revealed that the Ahmetusta member (Kua), Sunduk member (Kus), marble, granite, and limestone-sandstone blocks within the Ulus formation were not included in the study area. The Yemislicay formation (Ky) named by Ketin and Gumus (1963) contains mainly island-arc volcanism products. The formation has pelagic and semi-pelagic limestone units along with tuff, tuffite, agglomerate, conglomerate, sandstone, micrite, shale, and volcanics. The Akveren formation (KTa) named by Ketin and Gumus (1963) starts with sandy limestones at the bottom and continues with clayey limestones, reef limestones, mudstones, marl with turbidites, and volcanics (Alan and Aksay 2002). The Yığılca formation (Ty) named by Kaya et al.

(1986) consists of mainly volcanogenic sandstone with thinly bedded marl levels and was accompanied by volcanic products such as andesite, basalt, tuff, and agglomerate. The Caycuma formation (Tc) named by Tokay (1954) contains a dominant sequence of sandstone, siltstone, claystone with limestone, agglomerate, tuffite, and marl intercalation. The talus unit (Qym) in the region consists of various sizes of limestone gravels and blocks moving downward slopes. Alluvial materials (Qal) in the creeks and stream beds and in the basins consist of gravel, sand, silt, clay, and mud sediments.

Materials and methods

This study first was involved with the field studies defining the slope movements and geometric features and second running a computer-based landslide susceptibility analysis. Material parts of this study are related to slope movements occurring on the geological formations and units of the study area. The methodology of this study consists of field studies for determining slope movements and running a landslide susceptibility analysis for the study area. The onset of this study was gathering the related documents and literature about the landslide history of the area and then included field works. Basic sources in this study include geology maps, topographic maps, and site investigation reports. After the initial phase, the areas with landslides were drawn on the hard copy topographic maps of 1:25,000 scale, and the features of the landslides were recorded in an inventory table. Topographic, geologic, stream, transportation, and settlement area files were digitally secured to be used in a geographic information system (GIS)
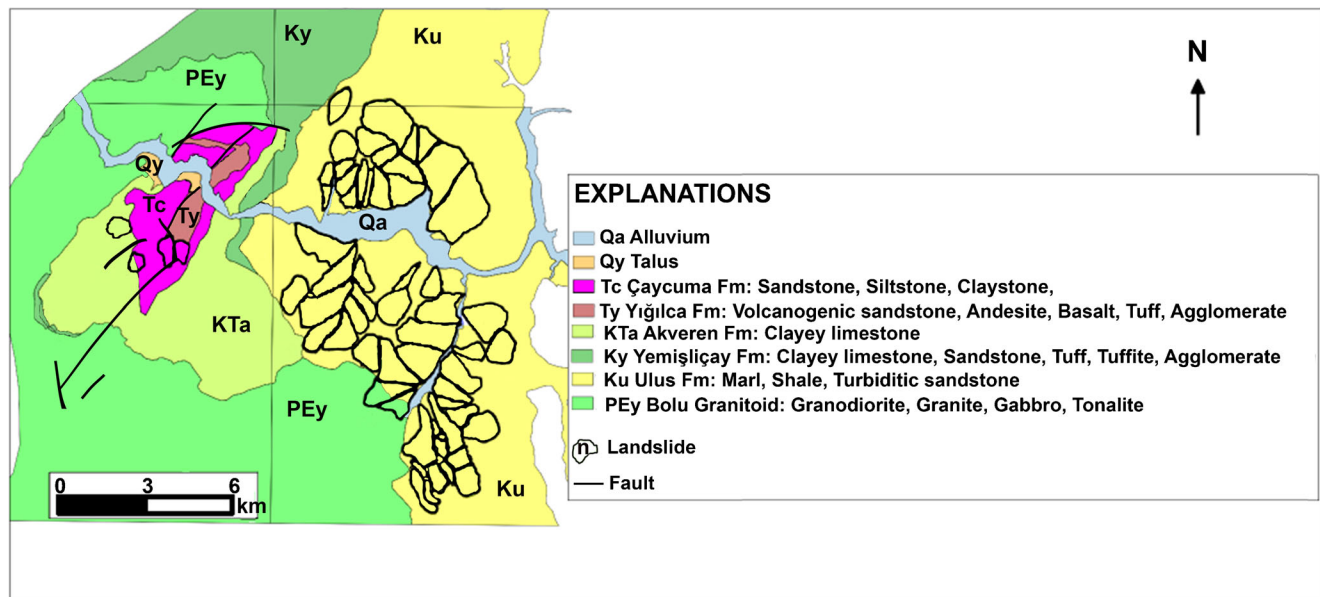
Fig. 2 Landslide locations on the geology map of the study area (geology map adopted from Alan and Aksay 2002)

into which the data obtained from the field works were logged. After completion of data logging to GIS, quantum GIS (qGIS) software processed the data to produce a digital elevation model (DEM) for the slope, aspect, and relief maps of the study area. In the analysis, the data belonging to the project conducted to determine the disaster risk potential of the Karabük province (Earthquake Research Department 2006) were used with granted permission by the Ministry of Public Works and Settlement and in the project the lowest distance without any confusion depending on the area size, 50 × 50-m resolution is used. Thus, all field data are combined in this resolution as layers in the GIS environment. Histograms and tables were prepared in the Microsoft Excel program to interpret the landslide data statistically. Then, the study area was analyzed for landslide susceptibility incorporating some crucial factors in landslide occurrence such as geology, slope, aspect, and distance to the river. The outcome maps were produced with relation to existing landslides, followed by the definition of frequency ratios. All the data layers with frequency ratios were overlaid to obtain a landslide susceptibility map by using ArcGIS 10 software. The locations of previous landslides defined by the fieldwork were superimposed on the landslide susceptibility maps to validate landslide susceptibility results and make evaluations and interpretations.

Field studies of slope movements

The types of slope movements observed in the study area are slide, flow, and fall, which were identified in situ by several field trips made to the area. Movement and material types, locations, and geometrical features of the mass movements were recorded during the field studies. Maps, a hand-held GPS receiver, camera, and landslide inventory table were used in field trips along the routes defined on the topography maps. Varnes (1978) slope movement classification was used to categorize the slope failures observed in the study area. According to this classification, slope movements are classified based on the first material type and the second type of movement. The areas in the study area affected by the different types of slope movements were drawn on topographic maps of 1:25,000 scale. Any information obtained from observations for the mass movements was entered into the inventory table. A map displaying locations of the mass movements and a table containing inventory data were prepared in the study. A total of 61 slope failures were defined during the field studies. A relation among the lithology, slope degree, and slope failure was noticed. Most slope failures (57) developed on the Ulus formation. The Akveren, Yığılca, and Caycuma formations had only four slope instability due to geological material type and slope factors. Figure 3 displays the mass movements occurred in the study area. The high-

altitude parts of the study area have a rugged morphology, which provides favorable conditions for the formation of mass movements. The earth slides are mainly seen in the claystone, siltstone, sandstone, and limestone alternations of the Cretaceous Ulus formation and partly in alluvial and talus. The upper altitudes of the earth slides are between 500 and 700 m (66% of total earth slides have a crown height between 500 and 700 m). The lower elevation of earth slides is generally approximately 100–200 m (these elevations are also elevations of Yenice and Filyos streams). In the study area, the lengths and widths of the earth slides vary from 500 to 1500 m and from 300 to 1600 m, respectively. The slopes of the earth slide areas in the study area are between 12 and 30 degrees and concentrate mainly on the slopes of 15 degrees. Changes in the study area morphology over time are noticeable during the fieldwork. It has been observed that there is a decrease in the degree of slopes in areas with recurrent landslides occurring in the region for a long time.

New landslides occur frequently in preexisting landslide areas. Most slope movements are rotational slides accompanied by flows (72% of the slope failures) and earth flows, debris flows, and debris earth flows (28% of the slope failures) occurred less frequently than the slides in the study area. Yergok et al. (1987) also defined most of the earth slides initiated as a slide and then accompanied with earth and debris flows and recurrent earth slides occurred in the Ulus formation, which was constituted by underwater landslides in the western Black Sea Region.

Slide type slope movements

Slide type slope movements are the most frequently observed mass movements in the study area. A slide is a downslope movement of a soil or rock mass occurring dominantly on surfaces of rupture or on relatively thin zones of intense shear strain (Cruden and Varnes 1996). The slides are mainly of a rotational type of slope movement observed in the slopes of the study area. Almost half of the study area is defined as areas with no sliding activity. These areas are topographically on flat lands located in the alluvial deposits, the products of flooding cycles of Filyos creek. Additionally, Yenice creek crossing Guney village formed flat areas with alluvial materials in the region. Most central districts of Yenice were constructed on these flat alluvial areas. Approximately, the areal coverage ratio of rotational earth slides is 36% in the study area. Especially, rotational slides were mainly developed on the slopes of the Cretaceous flysch and olistostrome units.

Some rotational slides display complex movements accompanied by earth flows and debris slides. It can be generalized that rotational slides develop on slopes with thick loose earth material moving downward as a massive body. Soil saturation due to precipitation, erosion at the bottom of slopes, or road cut along slopes and earthquake tremors are the triggering

Fig. 3 Map of the slope movements occurred in the study area
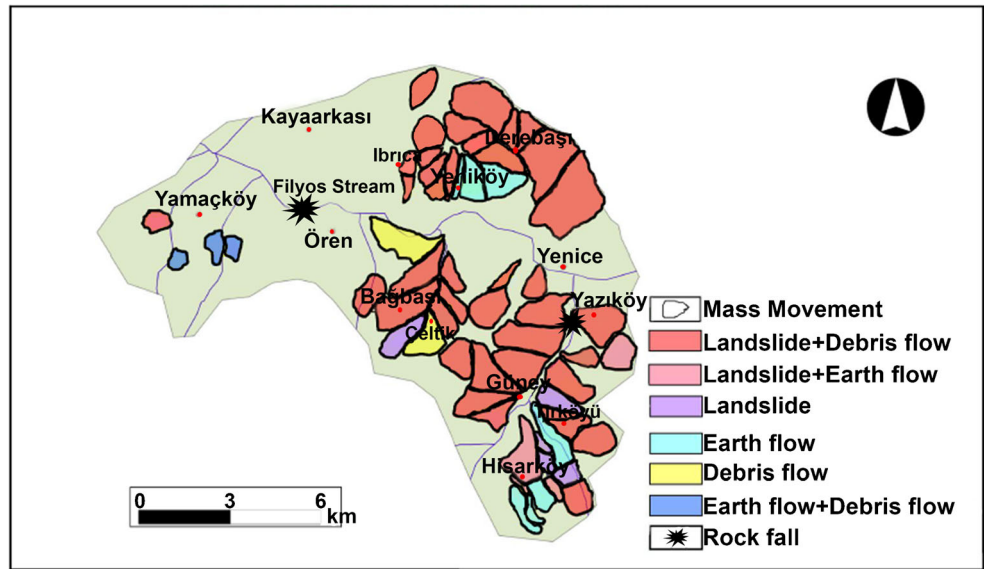
effects in the occurrence or reactivation of these types of landslides. The rotational slides are determined to have taken place on the slopes with varying inclinations from 14° to 20° according to field observations. Rotational type landslides have occurred mainly on slopes with the turbiditic Cretaceous flysch of the Ulus formation due to geodynamic and structural properties of the formation. Many folds and thrust faults as a result of the N-S compressional tectonic regime exist in the region, which intensively provide a suitable environment for earth slide development, and the majority of the folds overturned lead to unstable slopes. Some of the active earth

slides are called reactivated dormant earth slides based on the modified slope morphology noticed in the study area.

An example of a typical rotational type of slide in the region is the one occurring in Derebası Village of Yenice County. It activated in the 2000 year and damaged many houses built on a large area. Consequently, the Disaster and Emergency Management Authority of Turkey (AFAD) evacuated 31 damaged houses. The landslide occurred on a slope of a 20° inclination with 500 m length, 250 m width, and a maximum 25–30-m depth (Fig. 4). Within the scope of the disaster and hazard risk determination project of Karabük

Fig. 4 View of the Derebası landslide
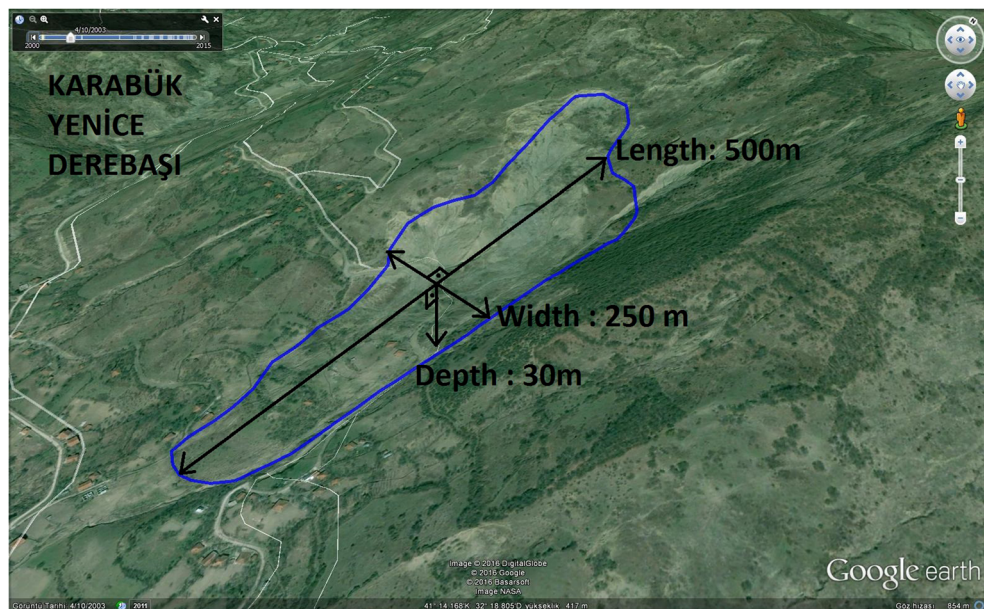
province by AFAD, the slide plane, geometric, and physical characteristics of the earth slide event that occurred in 2000 were investigated around Derebası village. Field studies included seismic refraction, vertical electric drilling, and microtremor measurements. The DES curves were evaluated to determine the earth slide geometry with vertical electric drilling. As a result of these studies conducted by the Earthquake Research Department (2006), the depth of the earth slide's sliding plane was determined to be 15-m depth. This depth corresponds to the deep depth of earth sliding according to Frehner et al. (2007) (Table 1).

Flow type slope movements

The second common slope movement type observed in the study area is flow. The first type flow movement is earth flow, which is a surficial mass movement controlled by topographic structure and mainly can be defined that surficial materials on bedrock move downward fast in an analogy to a viscose fluid flowing on a slope. Earth flows do not move along the shear strength failure surfaces as opposed to sliding type of mass movement. The earth flows of the study area mainly contained fine-grained materials with 90% of the particles smaller than 2 mm in the study area. They mainly occurred as independent movements of materials in moving mass. Earth flows were encountered either along slopes or valley bottoms in the study area. The second flow type movement is debris flow that occurred in the study area due to the coarse-grained material of the geological units and heavy rain. The grain sizes of materials involved in the flows vary from clay to boulder. Debris flows with coarse-grained materials occurred. Additionally, tree trunks and branches are mainly observed in some of the debris flows, while some earth flows are mainly triggered by a landslide in the study area. Especially in the Derebası location, earth flow occurred in the toe area of the landslide. Geological and topographic features of the study area contribute more often toward earth flow occurrences along the bottom of valleys. Slopes without surficial materials are mainly the result of the earth-flow process. Flowed materials are washed away by rain or transported by streams at the bottom of the slopes (Earthquake Research Department 2006). Debris slides can become extremely rapid debris flows or debris avalanches as

the displaced material loses cohesion, gains water, or encounters steeper slopes (Cruden and Varnes 1996).

Fall type slope movements

Another mass movement type seen in the study area is fall where developed in the bedrock as detached blocks. This type of movement seen in bedrock type material is classified as a rockfall (Varnes 1978). The study area has several cliffs and inclined bedrock slopes and is located in the third zone of the rockfall potential map prepared by the Disaster and Emergency Management Authority in 2006. This third zone is defined as a hazardous area with weak physical properties of rock material and possessing sensitive morphologic and geologic criteria (Earthquake Research Department 2006). Rockfalls were observed in the limestones of the Ulus formation around Yazıkoy and limestones of Akveren formation near the Kayaarkasi village along the Yenice-Zonguldak highway. Thus, rockfall potential is high in these two locations through the study area. The intersection of discontinuities (fractures, cracks, joints) with the bedding planes of the Ulus and Akveren limestones causes the rocks to be separated into blocks of different sizes with freeze-thaw cycles. These separated blocks occasionally fall from the rock mass by gravity.

Landslide susceptibility analysis

Landslide susceptibility analysis was performed for the study area. Landslide susceptibility is the likelihood of a landslide occurring in an area depending on local terrain conditions, estimating "where" landslides are likely to occur (Brabb 1984). The main purpose in developing a landslide susceptibility map is to define the potential areas for landslide and to compare the old landslide areas with newly defined landslide areas. The following sections explain the parameters used in the landslide susceptibility analysis and producing a landslide susceptibility map for the study area.
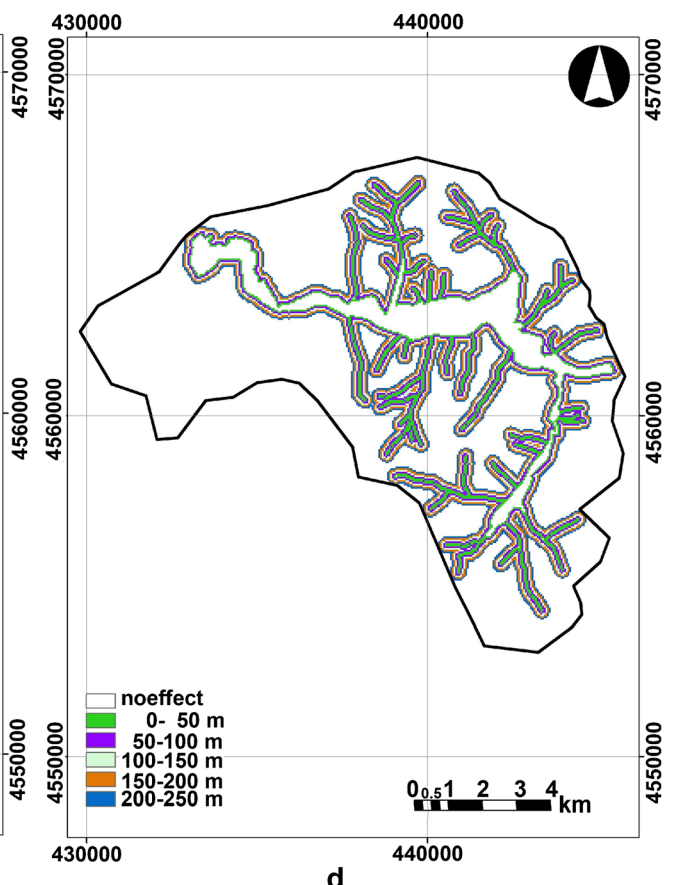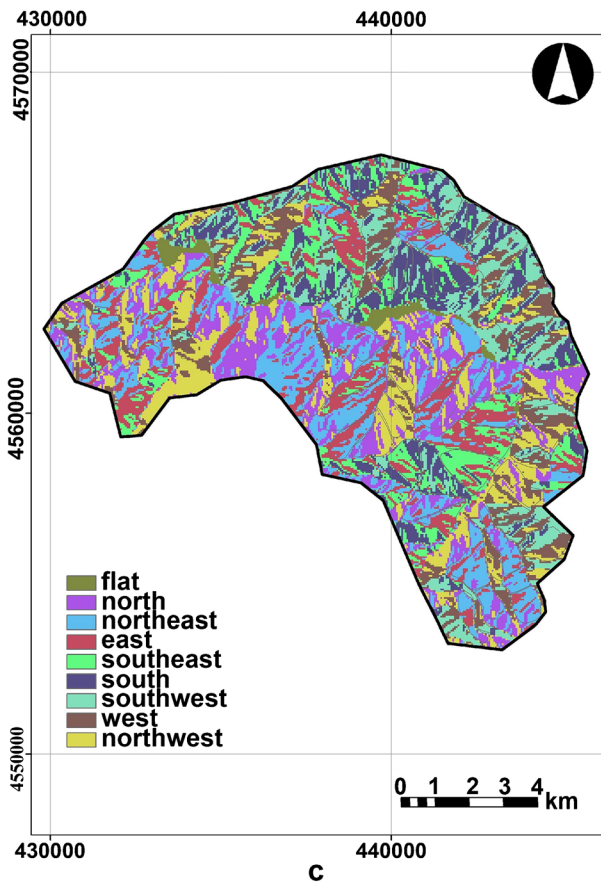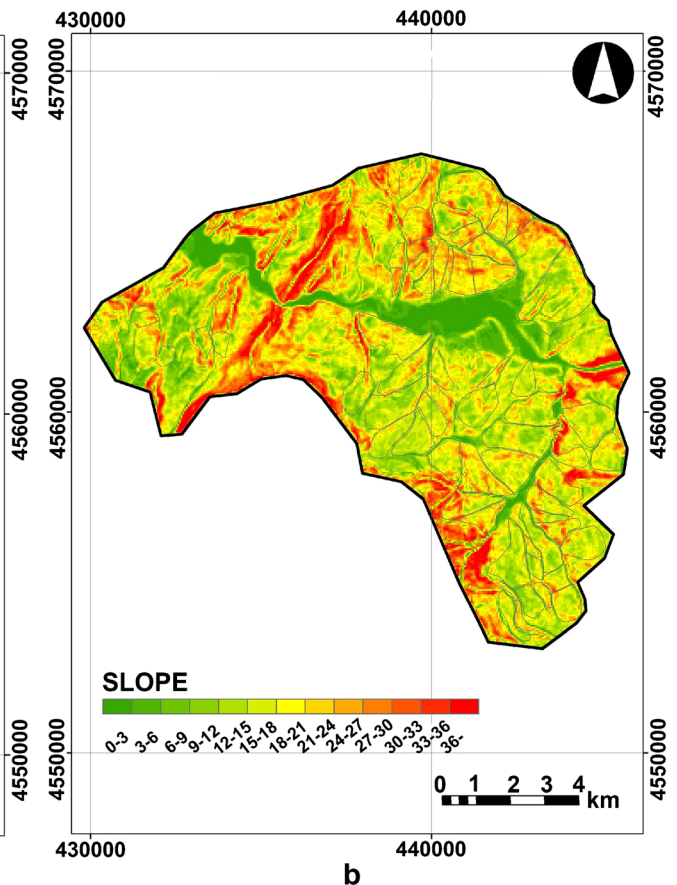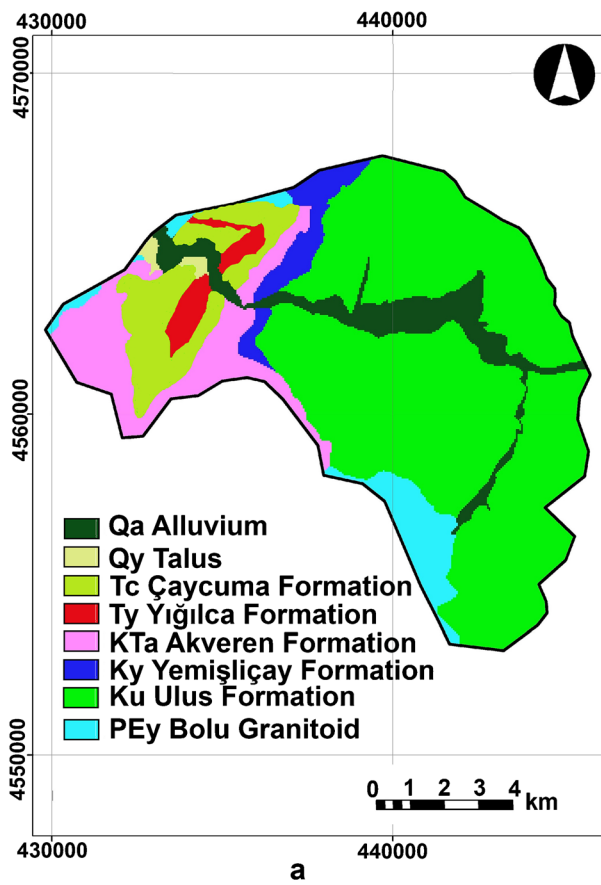
Parameters used in the susceptibility analysis

Four parameters were used in the analysis of landslide susceptibility of the study area, which are geology, slope, aspect, and distance to the river (Fig. 5). Literature studies and fieldwork conducted in the study area indicate that geology, climate, slope, distance to the river, and aspect factors are the main factors in the occurrence of landslides. The study area has a rainy climate due to being in the west of the Black Sea Region. The geological materials are usually wet, in other words, saturated with precipitation. Furthermore, because all landslide-prone areas in the region share the same climatic conditions, for this reason, the climate factor is excluded from landslide susceptibility analysis. The frequency ratio method based on

Table 1 Depth classification of landslides with areas (Frehner et al. 2007)

Depth (m)	Definition	Area (ha)
0–2	Shallow	Small (< 0.5)
2–10	Intermediate	Medium (> 0.5–10)
> 10	Deep	Large (> 10 up to several km^2)

a

Qa Alluvium
Qy Talus
Tc Çaycuma Formation
Ty Yığılca Formation
KTa Akveren Formation
Ky Yemişliçay Formation
Ku Ulus Formation
PEy Bolu Granitoid

b

SLOPE
0-3 3-6 6-9 9-12 12-15 15-18 18-21 21-24 24-27 27-30 30-33 33-36 36-

c

flat
north
northeast
east
southeast
south
southwest
west
northwest

d

noeffect
0- 50 m
50-100 m
100-150 m
150-200 m
200-250 m

the probability model is one of the widely used, easy to apply, and understandable methods in the production of landslide susceptibility maps (Lee and Talib 2005; Pradhan and Lee 2010a, 2010b; Yilmaz 2009; Yalcın et al. 2011). The frequency ratio is defined as the ratio of the probability of occurrence of an event to the probability of nonoccurrence (Bonham-Carter 1994; Lee et al. 2003; Lee et al. 2004; Lee and Evangelista 2005; Yilmaz 2009). The frequency ratio method is used to reveal the relationship between past landslide locations and each factor affecting landslide (Lee and Min 2001; Lee et al. 2004; Erener and Düzgün 2010). Since the landslides are recurrent in the study area, the frequency ratio method, which is the most common and applicable, is preferred to determine the relationship between landslide areas and factors affecting landslides. The factors that have a potential of causing the landslides determined in the study area are classified, and the frequency ratio for each factor is computed for each class. These frequency ratios computed are then used in the grading of the factors. The frequency ratios of parameters are calculated from Eq. (1).

$$FR = PLO/PIF \tag{1}$$

FR = frequency ratio

Here, PLO is the percentage of landslide occurrences in each subcategory of a factor that affects landslide and PIF is the percentage of each category of a factor that affects landslide (Lee and Min 2001; Lee et al. 2004; Lee and Pradhan 2007; Youssef et al. 2015; Wang et al. 2016; Erener and Lacasse 2007; Erener and Düzgün 2010). PLO is calculated as A/B and PIF as C/D in Table 2, where A refers to the pixel number of landslide area for each category, B refers to the total number of landslide cells, C refers to the pixel number of each category area, and D is for the total number of cells in the study area.

Geology

Geology is one of the parameters in defining landslide susceptibility of an area because it plays a crucial role in the determination of main geomorphologic data (Carrara et al. 1991; Anbalagan 1992; Pachauri et al. 1998; Dai and Lee 2001). For this reason, geology is considered an effective factor in landslide susceptibility studies. Factors such as the thickness of the weathered material, the type of lithology containing clay and silt (claystone, siltstone, and shale), and discontinuities in the same direction as the slope provide favorable conditions for the formation of mass movements geologically. For example, the slopes with the Ulus formation are particularly prone to mass movements verified by field studies. Although the Ulus formation is widespread in the study area, there are eight other formations and units covering half of the study area in the geology map. Thus, the geology map of the study area used in landslide susceptibility analysis is produced in ArcGIS version 10 (Fig. 5a) in raster format with 50×50-m pixel size. Numbers of pixels are computed for each geological formation or unit polygon area. Table 2 presents the frequency ratios calculated for the geological formations and units.

Slope gradient

The inclination degree of natural or cut slopes has a direct effect on the occurrence of landslides. This parameter is widely used in landslide susceptibility studies providing a rise in slope inclination increases the landslide susceptibility (Jakob 2000; Santacana et al. 2003; Ohlmacher and Davis 2003; Ayalew et al. 2004; Lee 2005; Fell et al. 2008; Dag and

Table 2 Frequency ratio values for geologic formations and units

Geologic formations and units	Landslide pixel number (A)	PLO (%)	Pixel number of each subclass (C)	PIF (%)	Frequency ratio PLO/PIF
Akveren formation	234	1.3066	5361	11.0627	0.1181
Ulus formation	16988	94.8626	29726	61.3413	1.5464
Çaycuma formation	205	1.1447	3467	7.15435	0.1600
Sunduk member	0	0	5	0.01032	0
Bolu Granitoid	383	2.1387	2711	5.5943	0.3823
Yığılca formation	98	0.5472	1197	2.47008	0.2215
Alluvium	0	0	3923	8.09534	0
Talus	0	0	285	0.58811	0
Yemişliçay formation	0	0	1785	3.68345	0
Total	17908 (B)	100	48460 (D)	100	2.4284

Bulut 2012). Generally, steeper slopes have a greater chance of landsliding (Varnes 1978). Since landsliding is directly related to the slope angle: the steeper the slope, the greater the tendency for instability (Hoek and Bray 1981). Zare et al. (2019) have defined the relationship between the slope and slip as linear with increasing the slope up to 40%, which caused the number of landslides to increase in the Mazandaran Province of Iran. The slope map was obtained using DEM in ArcGIS to analyze landslides for slope variations (Fig. 5b) with 50 × 50-m pixel size in which numbers of pixels are counted for each slope class polygon area. Slope values were divided into 13 classes from 0 to 36 degrees in 3-degree increments. Table 3 shows the frequency ratios calculated for the subcategories of slopes.

Slope aspect

Many researchers have indicated that the slope aspect is one of the important factors in generating landslide susceptibility maps (Dai and Lee 2001; Cevik and Topal 2003; Lee et al. 2003; Yalcın 2008). The aspect is directly related to the factors contributing to landslide development such as discontinuities, precipitation, wind effect, and exposure to sunlight (Gokceoglu and Aksoy 1996; Dai and Lee 2001; Cevik and Topal 2003; Ercanoglu et al. 2004; Yalcın 2008). Yenice is a place where rainfall is high due to the Black Sea climate. The direction of precipitation (wind originated) is important because the slopes facing the direction of rainfall are more exposed to water. Therefore, the ground receiving more water becomes more saturated, which can be prone to landslide events. Snow melts faster with rainwater, which means more water. The earth slides that occurred around Yenice in 1985 became active in 2017, because heavy rains immediately melted the snow on the slopes of Yenice terrain (Yilmaz and Atak 1985) before the earth sliding. Depending on the infiltration capacity controlled by more than one factor, such as heavy rainfall, topographic slope, soil class, permeability, porosity, moisture and organic matter content, vegetation cover, and the season of precipitation, the geological units on the slopes with dominant aspects get saturated faster than other slopes. Accordingly, this situation causes the development of pore water pressure on the slopes (Gokceoglu and Ercanoglu 2001; Yalcın 2008). An aspect map has been produced from DEM in ArcGIS to analyze slopes for various aspects in landslide susceptibility analysis with 50 × 50-m pixel size (Fig. 5c) in which the number of pixels is calculated for each aspect class in the aspect map. The aspect analysis classified the slopes for geographic directions. It was defined that most slopes are in NE and E directions in the study area. Frequency ratios calculated from the aspect values are shown in Table 4 for the study area.

Distance to the river

The distance to the river parameter is accepted as one of the contributing factors in landslide occurrences, which increases the susceptibility for sliding. Thus, this factor is used in the preparation of landslide susceptibility maps as an effective factor. Rivers can erode the bottom of slopes and saturate the eroded soil. Many researchers have used distance to the river parameter in landslide susceptibility analysis (Choubey and Litoria 1990; Choubey et al. 1992; Mejia-Navarro and Wohl 1994; Fernandez et al. 1999; Luzi and Pergalani 1999; Nagarajan et al. 2000; Peloquin and Gwyn 2000, Baeza and Corominas 2001; Barnard et al. 2001; Dai and Lee 2001; Gokceoglu and Ercanoglu 2001; Cevik and Topal 2003; Lee

Table 3 Frequency ratio values for slope subclasses

Slope subclasses	Landslide pixel number (A)	PLO (%)	Pixel number of each subclass (C)	PIF (%)	Frequency ratio PLO/PIF
0–3°	53	0.30	2280	4.70	0.0629
3–6°	176	0.98	1819	3.75	0.2619
6–9°	449	2.51	2322	4.79	0.5234
9–12°	1436	8.02	4010	8.27	0.9694
12–15°	3225	18.01	6668	13.76	1.3092
15–18°	4136	23.10	8136	16.79	1.3761
18–21°	3594	20.08	7230	14.92	1.3456
21–24°	2530	14.13	5586	11.53	1.2260
24–27°	1344	7.51	3786	7.81	0.9609
27–30°	606	3.39	2549	5.26	0.6436
30–33°	238	1.33	1723	3.56	0.3739
33–36°	95	0.53	1171	2.42	0.2196
> 36°	20	0.11	1180	2.43	0.0459
Total	17902 (B)	100	48460 (D)	100	9.3185

Table 4 Frequency ratio values for aspect subclasses

Slope directions	Landslide pixel number (A)	PLO (%)	Pixel number of each subclass (C)	PIF (%)	Frequency ratio PLO/PIF
Flat	0	0.00	769	1.59	0.0000
North	1582	8.84	6626	13.67	0.6463
Northeast	2980	16.65	7404	15.28	1.0895
East	2999	16.75	6234	12.86	1.3022
Southeast	1944	10.86	4812	9.93	1.0936
South	2367	13.22	5256	10.85	1.2191
Southwest	2209	12.34	5285	10.91	1.1314
West	2242	12.52	5696	11.75	1.0655
Northwest	1579	8.82	6378	13.16	0.6702
Total	17902 (B)	100	48460 (D)	100	8.2178

et al. 2003; Nefeslioglu et al. 2008; Akgun et al. 2008; Pradhan and Lee 2010a, 2010b; Dag and Bulut 2012). In the study area, the areas affected by the streams are drawn on the maps of 1:25,000 scale. To make an evaluation of the distance impact of a river, five buffer zones with 50 m were developed from each river (Fig. 5d). A raster distance to river map has been produced in ArcGIS with 50-m × 50-m pixel size, where numbers of pixels for each river impact subcategory are calculated in the raster proximity to the river map. Frequency ratios obtained using the distance to the river parameter are shown in Table 5. Frequency ratios are greater than one between 0 and 250-m river impact distances. Frequency ratios start to decrease after the first 150-m river impact distances and after 250-m river impact distances, the frequency ratios get lower than one. Table 5 presents river impact distances from 0 to more than 250 m by 50-m increment classes, pixel count of landslide areas, and frequency ratios.

Results

This study gathered detailed data about slope movements in the Yenice area and compiled these data to run a landslide susceptibility analysis for the study area. Field studies resulted in the determination of slope movement types and the preparation of a landslide inventory map for the study area. Later on, a landslide susceptibility map was generated using the GIS capabilities of ArcGIS software. Lithology, slope degree, slope aspect, and distance to river parameters were the basic layers in overlay analysis-conducted landslide susceptibility. Frequency ratios for subclasses of each parameter are computed by the frequency ratio method in ArcGIS. The landslide susceptibility map has been prepared by overlaying the raster maps of each parameter according to the frequency values using the weighted sum overlay command under the spatial analyst tools menu. Frequency ratio values are directly used in the overlay analysis. Areas with frequency ratios greater than one are accepted as more risky areas for earth sliding. The landslide susceptible map is categorized into five classes as very low, low, moderate, high, and very high in terms of susceptibility, and the study area had five landslide susceptibility categories with different sizes and spatial distribution. Out of five susceptibility classes, the high and very high susceptibility classes reflect areas with geologic units prone to landslides such as the Ulus and Çaycuma formations, high inclined slopes (15°–30°), sensitive aspect directions (NE, E), and river impact distances between 0 and 250 m. Figure 6 displays the landslide susceptibility map obtained

Table 5 Frequency ratio values for river impact distance subclasses

River impact distance (m)	Landslide pixel number (A)	PLO (%)	Pixel number of each subclass (C)	PIF (%)	Frequency ratio PLO/PIF
0–50	1586	8.87	3440	7.10	1.2495
50–100	1706	9.54	3344	6.90	1.3827
100–150	1670	9.34	3174	6.55	1.4260
150–200	1535	8.59	2990	6.17	1.3914
200–250	1403	7.85	2825	5.83	1.3460
> 250	9980	55.82	32687	67.45	0.8275
Total	17880 (B)	100	48460 (D)	100	7.6232

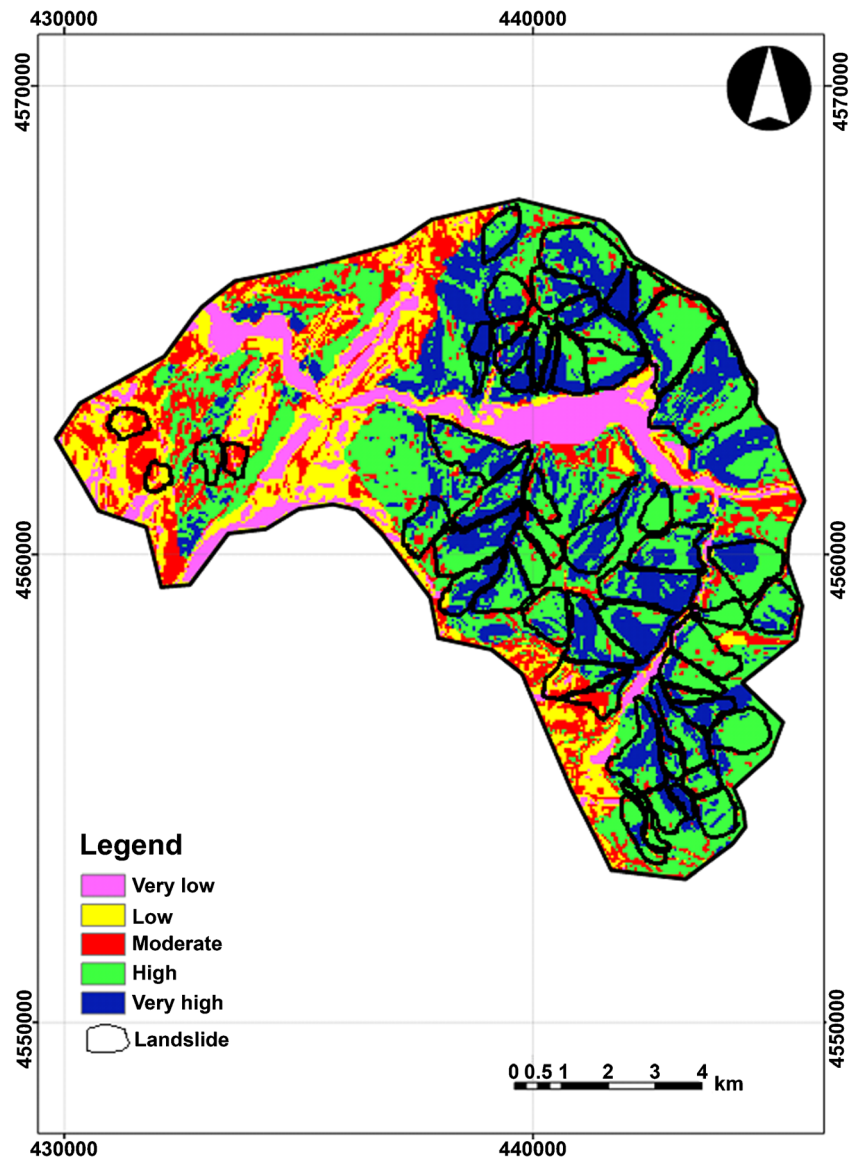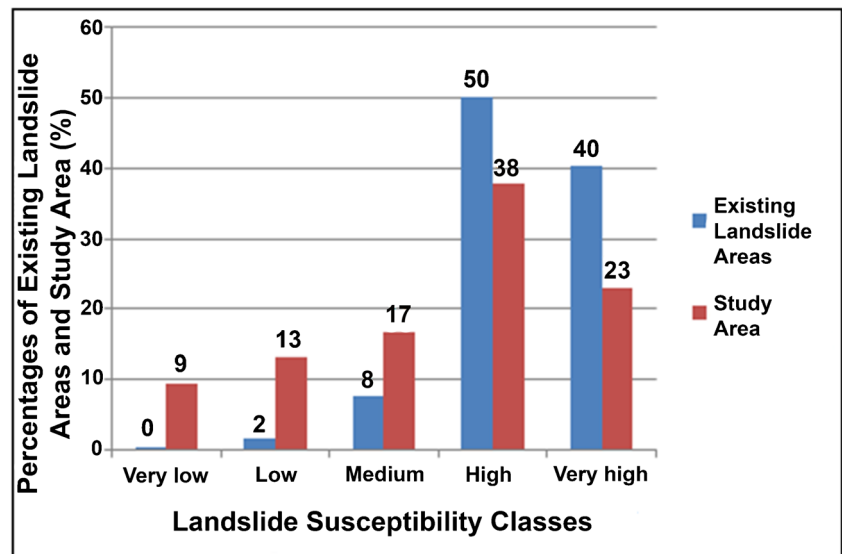**Fig. 6** Landslide susceptibility
map of the study area

Fig. 7 Comparison of existing
landslide areas with susceptibility
classes

in this study, which simply presents the geographic distributions of the landslide susceptibility classes and their areal extents in the study area. When the landslide susceptibility map of the study area is compared with Ercanoglu et al. (2016) research results, it was observed that the susceptibility areas overlapped. Due to the formation of Ulus formation by underwater landslides (Yergok et al. 1987), having recurrent landslides due to its lithological characteristics and covering a large area in the study area, the areas with landslide susceptibility coincide with the landslide inventory map showing the existing landslides. The landslide susceptibility map of the study area shows areas with landslide potential that have not yet been exposed to landslides but also revealed that the landslide areas within the Ulus formation could be exposed to landslides again. The high annual precipitation occurring in and around Yenice is the main triggering factor of slope instability, especially in winter and spring.

Validation of the landslide susceptibility analysis

Validation of the landslide susceptibility has been checked by correlating the areas of susceptibility classes with respect to the existing landslide areas. Very low, low, moderate, high, and very high susceptible areas were obtained in the landslide susceptibility map. Areal distribution percentages of susceptible areas are 9% very low, 13% low, 17% moderate, 38% high, and 23% very high. The high susceptible class has the highest susceptibility in areal extent and the study area contained 61% of high and very high susceptibility areas. The percentages of susceptible areas were calculated through the pixel values of each class divided into the entire study area pixel value. Areal percentages of existing landslides were calculated through the GIS area calculation option for polygon graphics. To compare the landslide susceptibility areas with existing landslide areas, the graph in Fig. 7 was produced and the percentage values were obtained. As seen in this graph, it was determined that high and very high susceptible areas approximately 61% of the study area cover 90% of the existing landslide areas (see Figs. 6 and 7). This result indicates that defining landslide susceptible areas via GIS capabilities is high. Similarly, Sahin (2018) has developed stepwise regression landslide susceptibility analyses for the Yenice-Karabük area and calculated a validation value of approximately 88% for the model-6. Ercanoglu et al. (2016) have run landslide susceptibility for the Yenice area and obtained the validation of the susceptibility analysis through the AUC method as 0.873 (87.3%). Ercanoglu (2005) has evaluated the performance of the landslide susceptibility model in three ways such as (1) a measure of goodness of fit (87.2%), (2) a similarity approach (85%), and (3) an independent validation strategy

(82.5%) for the SE Bartın in the west Black Sea Region of Turkey.

Conclusions

This study evaluated the slope movements in the Yenice area and is one of the first slope movement analysis studies conducted for the study area. Previously occurring slope movements were defined, and landslide susceptibility analysis was performed around Yenice and its villages. Slide, flow, and fall types of slope movements were observed in the field. The most common slope movements were earth slides and earth flows. Rockfall affecting just a part of the highway was seen only in two locations. A landslide susceptibility map was produced in the second stage of the study using the frequency ratio method. Although susceptibility analysis was run by one method with four predisposing parameters, the results for identifying susceptible areas were satisfactory. The frequency ratio method is a fast and easily applicable method with adequate data. This method was used to illustrate the relationship between past landslides and parameters contributing to landslide occurrence. The landslide susceptibility analysis identified areas with landslide potential and determined the spatial distribution and areal extent of these areas. Landslide areas were used in the calculation of frequency ratio values that were computed for each category of a parameter-contributing landslide. Frequency ratio values were directly used in ArcGIS to obtain a landslide susceptibility map. GIS made it easy and fast to handle spatial data for generating the landslide susceptibility map. The geology parameter defined the geological formations and units in the study area. The morphology of the study area is evaluated in terms of slope degrees and altitudes. The distance to the river parameter is defined as the specific distances between the slopes and flowing water in a stream, river, or creek. The slope aspect is used for defining the effects of precipitation, wind, and climatic conditions on the slopes of the study area. Aspect analysis has indicated that the most prominent land sliding directions are northwest and east in the study area.

The landslide susceptibility map has been developed based on four major factors contributing to slope instability. Previously occurred landslide areas were overlaid on high and very high susceptible areas and they included 90% of old landslide areas. This outcome proves that the accuracy rating of the landslide susceptibility map is quite high. The landslide susceptibility map of the study area can be used by planners and engineers for locating new appropriate development sites in the Yenice area and for adopting appropriate mitigation measures in defined disaster-prone areas. Outcomes of this study can be guidance for municipality and governorship in implementing prevention measures against mass movements and defining new development and safe

areas for the people of Yenice. Determination of areas with and without landslide potentials in the study area would provide a more secure and economical design of engineering structures such as dams, bridges, tunnels and highways, and infrastructures and superstructures to be constructed in these areas. Additionally, mass movement hazard zoning for land use planning can be implemented based on the landslide susceptibility map.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Competing interests The authors declare that they have no competing interests.

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