TÜBİTAK

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2014) 38: 281-290
© TÜBİTAK
doi:10.3906/tar-1303-12

# Assessment of forest road conditions in terms of landslide susceptibility: a case study in Yığılca Forest Directorate (Turkey)

**Remzi EKER*, Abdurrahim AYDIN**
Faculty of Forestry, Düzce University, Düzce, Turkey

**Received:** 04.03.2013 • **Accepted:** 25.07.2013 • **Published Online:** 27.01.2014 • **Printed:** 24.02.2014

**Abstract:** Forest roads are one of the biggest investments in forest management. Their possible adverse effect on the environment is becoming an important issue for administrators due to a recent increase in public awareness. Especially in the Black Sea Region of Turkey, road-related landslides are common in forested areas because the roads are located in hilly regions with steep slopes. In addition to their impact on forests, landslides can cause damage to roadbeds which requires immediate maintenance. Landslide-susceptibility maps are widely used for different purposes such as reducing the effects of landslides, decision making, and planning. These maps can easily be generated by utilizing the advanced features of Geographical Information Systems (GIS) and computer technologies. Logistic regression (LR) is a widely used technique for mapping landslide susceptibility; landslide conditioning parameters such as topography, lithology, land use, distance to streams and roads, and curvature can be mapped by GIS tools. In this study a fieldwork-generated inventory of 288 landslides was used to produce a landslide-susceptibility map for the Yığılca Forest Directorate (Turkey). This map was generated by applying a GIS-based LR method. Land use, lithology, elevation, slope, aspect, distance to streams, distance to roads, and plan curvature were considered as the landslide conditioning parameters. After the landslide-susceptibility map was divided into 5 classes of susceptibility (very low, low, moderate, high, and very high), it was overlapped with a road network map in order to evaluate forest road conditions in terms of landslide susceptibility. For a quantitative analysis of forest road-landslide interaction, 2 new parameters were determined: a landslide frequency index (divided into general and real) and a road-landslide index (divided into general and real). Real landslide frequency and general landslide frequency on the roads were found to be 0.42 and 0.18, respectively. The results showed that the real road-landslide index and the general road-landslide index in the area were 0.10 and 0.04, respectively.

**Key words:** Forest road networks, landslide frequency, landslide susceptibility, logistic regression, road-landslide index, Yığılca

## 1. Introduction

Landslides are common natural disasters comparable to others such as earthquakes, floods, and storms. A landslide that occurs suddenly and causes severe loss and damage is defined as "the perceptible downward sliding or falling of a relatively dry mass of earth, rock, or a mixture of the two (Sharpe, 1938)" in *Glossary of Geology and Related Sciences* from the American Geology Institute. Landslides are generally triggered by rapid snowmelt, rainstorms, earthquakes, and volcanic eruptions (Malamud et al., 2004; Duman et al., 2005). In addition to these natural factors, there are man-made factors such as road construction (Coker and Fahey, 1993; Wemple et al., 2001), forest management practices (Jacob, 2000; Dhakal and Sidle, 2003), agricultural activities (Wachal and Hudak, 2000), and mining (Marschalko and Treslin, 2009).

Landslide-susceptibility mapping has become a widely used method in landslide assessment studies because of the increasing adverse effects of landslides on human life and property. Particularly in the last 2 decades, it has become an important subject for earth scientists, engineers, planners, and decision makers (Ercanoğlu and Gökçeoğlu, 2002). Since the early 1970s many scientists have attempted to produce susceptibility maps, often applying Geographical Information System (GIS)-based techniques (Vahidnia et al., 2010). Methods of landslide assessment have been classified into 2 approaches: qualitative and quantitative (Aleotti and Chowdhury, 1999). Logistic regression (LR), which is used to analyze the relationship between the categorical or binary response variable and one or more categorical or binary explanatory variables (Bai et al., 2008), is a statistical technique used in the quantitative method of landslide assessment. LR has been widely used by many researchers for mapping landslide susceptibility (Ayalew and Yamagishi, 2005; Nefeslioğlu et al., 2008; Kıncal et al., 2009; Erener and Düzgün, 2010; Akgün, 2011; Ercanoğlu and Temiz, 2011; Süzen and Kaya, 2011).

---

* Correspondence: remzieker@duzce.edu.tr

Forest roads are constructed to provide sustainable, safe access to forested lands for forest management activities such as logging operations, transportation of timber to mills, forest conservation, and forest planning (Hasmadi et al., 2008). Forest roads, one of the biggest investments in forest management, are complex engineering structures that require proper construction methods. Proper road construction and maintenance activities are especially important in the case of forests that are located in mountainous areas, forests that have a low yield of merchantable logs per unit area, and forests located in areas receiving high precipitation (Hasmadi et al., 2008). Roads pose a variety of potential and actual risks to the natural systems in which they are constructed (Jones et al., 2000; Girvetz and Schilling, 2003).

The important factors influencing slope stability are pore water pressure, soil strength parameters, slope steepness, and depth to the potential failure plane (Sidle et al., 1985). One of the negative effects of roads is the loss of forest area due to the influence of their construction on slope hydrology (Sorkhi et al., 2012). Arıcak et al. (2010) stated that 0.6–1 ha of forest area, corresponding to 400–3500 trees (depending on forest age), must be clear-cut for the construction of each kilometer of forest road. It is inevitable that road construction on any hill slope will render the slope unstable. Factors contributing to this instability include: added weight to the slope in the embankment fill, steeper slopes on both cut and fill surfaces, removal of the cut-slope support, and re-routing and concentrating road drainage water (Sidle et al., 1985). Coker and Fahey (1993) stated that a total of 263 slope failures of all types, including rotational slide, topple, earth flow, etc., were recorded over 142 km of roads during a survey in Golden Downs and Motueka Forests. This is equivalent to a sediment yield of 142,000 $m^3$. It was also stated in their study that the total volume of displaced material over a 209-km road network amounted to 193,000 $m^3$ of granite, corresponding to 80 years of sediment yield from surface erosion. In a study in the western Cascade Range (Oregon, USA), the volume of slide material moved from a right-of-way area was 30 times that of slide activity in undisturbed forested areas (Swanson and Dyrness, 1975). In addition, Allison et al. (2004) stated that roads increase landslide occurrence 25–350 times in steep and unstable terrain compared to undisturbed forested land.

The impact of landslides on a road network depends on the type of landslide, the location of the roads, and the geomorphology of the area (Reichenbach et al., 2002). The occurrence of landslides can make roads unusable because the resulting displaced material can block roads as well as destroy roadbeds, creating serious maintenance costs. Heam et al. (2007) stated that in Lao PDR, the cost of emergency repair work due to landslides and their related effects was between US$ 1000 and 1500 per kilometer of road per year. In Turkey, 70 million Turkish Lira has been expended in the last 10 years for the emergency maintenance of 8973 km of roads (General Directorate of Forestry, Turkey).

Other issues relating to forest road networks are planning, construction, and maintenance. Many forest engineers still use traditional methods that are entirely manual for determining road locations (Hosseini et al., 2012). As a result of selecting inappropriate road locations, adverse impacts on the natural environment emerge in conjunction with the occurrence of technical and economic problems (Görcelioğlu, 2004). Because of the increasing public awareness of environmental issues over the last few years (Gümüş et al., 2008), forest engineers are searching for suitable approaches that reduce costs and increase efficiency, as well as those that minimize the adverse impact of roads on forests (Radfar et al., 2011). Thus, determining the road location is the most difficult stage of road network planning. Landslides have to be taken into account in forest road planning as well as in land management. Particularly in mountainous regions, road construction causes increased slope stability problems and higher road maintenance costs. These costs are directly related to stability problems like landslides. The influence of road construction on slope failure depends on site conditions and construction techniques. Landslide-susceptibility maps can be used as a basis for selecting appropriate road locations, for determining required engineering road construction standards, and for minimizing construction and maintenance costs related to landslides.

## 2. Materials and methods

### 2.1. Study area

The Yığılca Forest Directorate was selected as the study area because it is located in the landslide-prone Western Black Sea Region of Turkey (Figure 1). It consists of 5 forest districts: Boğabeli, Karakaş, Karagöknar, Karadere, and Melendere. The exact location of the study area is within N41°2.230′ and 40°47.597′ and E31°16.186′ and 31°41.974′, and covers 499 $km^2$ (49,874 ha). According to road network plans, 931.9 km of roads, including forest roads, village roads, and motorways, were to be constructed in the study area. Of the proposed roads, about 866.3 km (93% of the roads in the network plan) has been constructed to date. The distribution of these roads in the network plan, as per forest district, is shown in Table 1.

### 2.2. Data preparation and landslide inventory

In the present study an inventory of 288 landslides was generated through fieldwork. Of the recorded landslides, 188 were rotational slides, 62 were flow, and 38 were translational slides. The sizes of the landslides varied

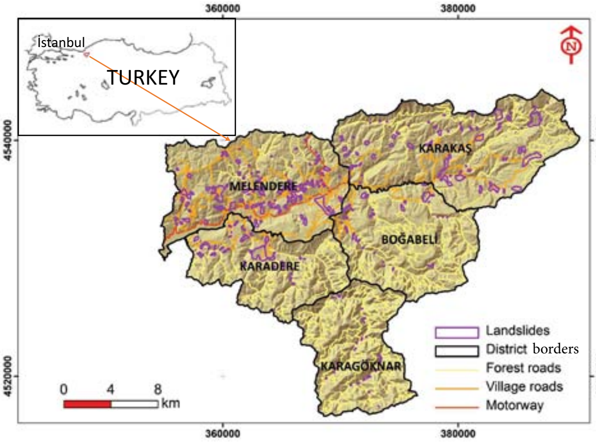

**Figure 1.** Location map of the study area.

between 1140 m$^2$ and 1,182,391 m$^2$. A landslide-inventory map was then generated in vector format using GIS software.

Based on the observations in the field studies, 8 landslide conditioning parameters were selected for the landslide-susceptibility mapping: land use, lithology, elevation, slope, aspect, distance to streams, distance to roads, and plan curvature (Figure 2). The lithology data were obtained from the Mineral Research and Exploration General Directorate (MTA). Land use data in vector format were produced from digitized maps of forest stand types obtained from the Yığılca Forest Directorate. The other parameters were obtained in raster format by using the digital elevation model (DEM) of the study area. All parameter maps and landslide-inventory maps were converted and stored in a raster format containing 9,893,637 pixels with 10 m × 10 m resolution. Of these, 151,084 pixels represented landslides, each of which was given a 1-pixel value in the landslide-inventory parameter. They were formed by 3573 columns and 2769 rows.

After obtaining maps of all the conditioning parameters, these parameters were compared with the landslide-inventory map (Ercanoğlu and Temiz, 2011). Lee and Talib (2005) stated that the relationship between areas where a landslide has occurred and landslide conditioning factors can be distinguished quantitatively from the relationship between areas without past landslides and landslide conditioning factors by using the frequency ratio (FR) method. Therefore, the parameter maps were classified, and the number of pixels in each class was calculated. The FR of all classes was calculated by constructing a table for each parameter map (Table 2).

**Table 1.** Road length distribution in forest districts.

| Forest district | Road length in network plan (km) | Constructed road length (km) |
|---|---|---|
| Melendere | 214.1 | 207.9 |
| Karagöknar | 181.1 | 162.6 |
| Karadere | 137.6 | 130.6 |
| Karakaş | 205.7 | 195.2 |
| Boğabeli | 190.3 | 167.0 |

### 2.3. Logistic regression application

The LR method is used for the same objectives as other regression models. The response variable in LR is binary or dichotomous, which is characteristic of LR as distinguished from linear regression models (Hosmer and Lemeshow, 2000). The goal of LR in mapping landslide susceptibility is to find the best-fitting model using the relationship between the presence or absence of landslides and a set of explanatory variables (Ayalew and Yamagashi, 2005). This relationship between the presence of landslides and explanatory variables can be expressed quantitatively in Eq. (1) (Lee, 2005):

$$p = 1/(1+e^{-z}) \tag{1}$$

where $p$ is the probability of an event occurring which varies from 0 to 1. The value $p$ in the present situation is the probability of a landslide occurrence, and $z$ is the linear combination which is shown in Eq. (2):

$$z = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n \tag{2}$$

where $b_0$ is the intercept of the model, $b_i$ (i = 1, 2, …, n) are the coefficients of the explanatory variables of the model, and $x_i$ (i = 1, 2, …, n) are the explanatory variables.

The LR method was applied with the LOGISTIREC module of Idrisi Selva 17.0, which uses a maximum likelihood estimation procedure to find the best-fitting set of explanatory parameters. The LR model was performed with 10% stratified random sampling procedure. Maximum likelihood can be expressed in the following equation:

$$L = \prod_{i=1}^{N} \mu_i^{y_i} \times (1-\mu_i)^{(1-y_i)} \tag{3}$$

where $L$ is the likelihood, $N$ is the number of samples, $\mu_i$ is the predicted value of the dependent variable for sample $i$, and $y_i$ is the observed value of the dependent variable for sample $i$.

The LR models applied in the present study were calculated by the LOGISTIREC module, where –2log(L0) explains L0 is the value of the likelihood function if all coefficients except the intercept are 0, and where –2log(L) depicts likelihood as the value of the likelihood function

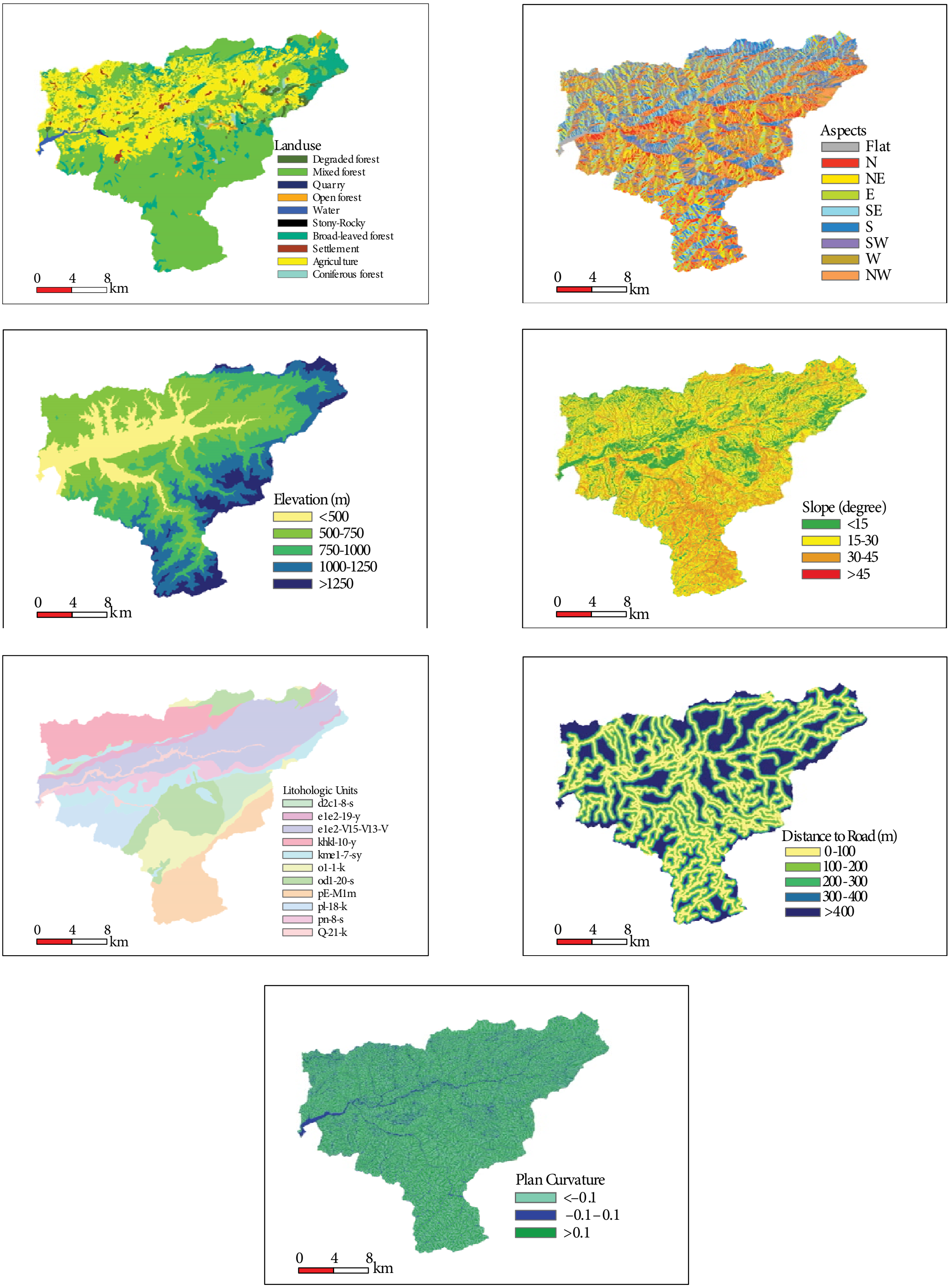

**Figure 2.** Input parameter maps.

**Table 2.** Distribution of each parameter class and FR values.

| Parameter class | LP | P | FR = LP/P | Parameter class | LP | P | FR = LP/P |
|---|---|---|---|---|---|---|---|
| Land use | | | | Distance to road (m) | | | |
| Settlement | 4.32 | 1.11 | 3.90 | 0–100 | 39.20 | 31.71 | 1.24 |
| Mixed forest | 13.61 | 52.43 | 0.26 | 100–200 | 25.71 | 21.77 | 1.18 |
| Broad-leaved forest | 7.73 | 11.12 | 0.69 | 200–300 | 14.74 | 15.62 | 0.94 |
| Degraded forest | 3.48 | 1.37 | 2.54 | 300–400 | 8.35 | 10.86 | 0.77 |
| Water | 0.00 | 0.47 | 0.00 | >400 | 12.00 | 20.04 | 0.60 |
| Open forest | 0.02 | 0.44 | 0.04 | Plan curvature | | | |
| Coniferous forest | 0.07 | 0.49 | 0.14 | <−0.1 | 46.39 | 41.61 | 1.11 |
| Stony-rocky | 0.00 | 0.02 | 0.00 | −0.1–0.1 | 9.43 | 9.67 | 0.97 |
| Quarry | 0.04 | 0.07 | 0.57 | >0.1 | 44.18 | 48.72 | 0.91 |
| Agriculture | 70.74 | 32.47 | 2.18 | Slope (°) | | | |
| Distance to stream (m) | | | | <15 | 39.95 | 25.93 | 1.54 |
| 0–50 | 28.94 | 25.61 | 1.13 | 15–30 | 49.40 | 50.95 | 0.97 |
| 50–100 | 20.80 | 20.46 | 1.02 | 30–45 | 10.03 | 22.35 | 0.45 |
| 100–150 | 14.96 | 16.65 | 0.90 | >45 | 0.62 | 0.77 | 0.81 |
| 150–200 | 10.91 | 12.48 | 0.87 | Lithology | | | |
| 200–250 | 7.83 | 8.77 | 0.89 | e1e2-V15-V13-V2-s | 53.60 | 23.13 | 2.32 |
| 250–300 | 5.62 | 5.88 | 0.95 | od1-20-s | 3.61 | 12.42 | 0.29 |
| 300–350 | 4.14 | 3.75 | 1.10 | pE-M1m | 1.17 | 11.91 | 0.10 |
| 350–400 | 2.53 | 2.26 | 1.12 | kme1-7-sy | 17.80 | 9.82 | 1.81 |
| >400 | 4.27 | 4.13 | 1.04 | khkl-10-y | 11.97 | 14.44 | 0.83 |
| Aspects | | | | o1-1-k | 0.68 | 7.69 | 0.09 |
| Flat | 1.35 | 2.61 | 0.52 | e1e2-19-y | 7.39 | 3.14 | 2.35 |
| N | 11.14 | 12.90 | 0.86 | d2c1-8-s | 1.85 | 4.11 | 0.45 |
| NE | 11.58 | 10.39 | 1.11 | Q-21-k | 0.00 | 2.04 | 0.00 |
| E | 11.44 | 10.46 | 1.09 | pl-18-k | 1.51 | 6.33 | 0.24 |
| SE | 9.83 | 11.52 | 0.85 | pn-8-s | 0.41 | 4.98 | 0.08 |
| S | 11.94 | 11.75 | 1.02 | Elevation (m a.s.l.) | | | |
| SW | 11.96 | 11.62 | 1.03 | <500 | 41.52 | 16.57 | 2.51 |
| W | 15.12 | 13.64 | 1.11 | 500–750 | 36.96 | 34.95 | 1.06 |
| NW | 15.64 | 15.12 | 1.03 | 750–1000 | 12.70 | 24.14 | 0.53 |
| | | | | 1000–1250 | 8.76 | 17.12 | 0.51 |
| | | | | >1250 | 0.06 | 7.21 | 0.01 |

LP: percentage of landslide-affected pixel; P: pixel percentage in each subgroup; e1e2-V15-V13-V2-s: pyroclastic rocks-andesite-basaltic; od1-20-s: sandstone-mudstone-limestone; pE-M1m: metagranitoid; kme1-7-sy: argillaceous limestone, khkl-10-y: volcanic sedimentary rock; o1-1-k: sandstone; e1e2-19-y: sandstone-mudstone; d2c1-8-s: limestone, Q-21-k: quaternary-alluvium; pl-18-k: terrestrial clastics; pn-8-s: limestone (Paleocene faunal).

for the full model as fitted. Pseudo $R^2$, which indicates how the LR model fits the data set, and chi-square, which tests the hypothesis that all coefficients except the intercept are 0, can be expressed in the following equations:

$$PseudoR^2 = 1 - (\log(likelihood) / \log(L0)) \quad (4)$$

$$Chisquare(k) = -2(\log(likelihood) - \log(L0)) \quad (5)$$

The goodness-of-fit statistic was calculated based on the difference between the observed and predicted values of the depended variable, as shown in Eq. (6). The smaller the statistic means the better the fit.

$$Goodnessoffit = \sum_{i=1}^{N} (y_i - \mu_i)^2 / \mu_i \times (1 - \mu_i) \quad (6)$$

The landslide-susceptibility map generated with LR was divided into 5 susceptibility classes including very low susceptibility (0–0.2), low susceptibility (0.2–0.4), moderate susceptibility (0.4–0.6), high susceptibility (0.6–0.8), and very high susceptibility (0.8–1). Area under the curve (AUC) value was used for validation of the susceptibility map generated. The AUC value was calculated using the true positive percentage and the false positive percentage values for each class that constitutes the curve. The relative operating curve (ROC) module of Idrisi Selva 17.0 software was used for this. The AUC value can be expressed in Eq. (7) as:

$$AUC = \sum_{i=1}^{N} [x_{i+1} - x_i] \times [y_i + (y_{i+1} - y_i)/2] \quad (7)$$

where $x_i$ is the false positive percentage in the value of $i_{th}$ threshold, and $y_i$ is the true positive percentage in the value of $i_{th}$ threshold.

### 2.4. Overlaying road network and the landslide-susceptibility map

An overlay analysis was made using the forest road network and the landslide-susceptibility map to determine the distribution of roads in susceptibility classes and to evaluate them in terms of landslides. It was necessary to convert the classified landslide-susceptibility map from raster format to polygon vector format in order to overlay the road network. After overlay analysis, the distribution of road types in forest districts in the study area was determined.

In the present study, landslide frequency, defined as the number of landslides located over a road route per kilometer of road, was calculated (Wemple et al., 2000). Furthermore, landslide frequency was categorized and formulized as general landslide frequency and real landslide frequency. General and real landslide frequency values were calculated using the following equations:

$$GLF = \frac{\sum NL}{\sum RL} \quad (8)$$

$$RLF = \frac{\sum NL}{\sum RRL} \quad (9)$$

where *GLF* is the general landslide frequency, *RLF* is the real landslide frequency, $\Sigma NL$ is the sum of the number of landslides located over road routes, $\Sigma RL$ is the sum of lengths of all road routes in the area (regardless of landslide occurrences), and $\Sigma RRL$ is the sum of road route lengths where landslides have occurred (only routes with landslide occurrences).

In the present study, the road-landslide index term was defined and categorized as general road-landslide index and real road-landslide index. The aim of describing these index values was to determine how many roads were directly affected by landslides. While the general road-landslide index can be defined as the ratio of length of road routes in the landslide area to total length of road routes (regardless of landslide occurrences), the real road-landslide index value can be defined as the ratio of length of road routes in the landslide area to the sum of road route lengths where landslides have occurred (only routes with landslide occurrences). Road-landslide index values were calculated using the following equations:

$$RLI_g = \frac{\sum RL_i}{\sum RL} \quad (10)$$

$$RLI_r = \frac{\sum RL_i}{\sum RRL} \quad (11)$$

where $RLI_g$ is the general road-landslide index, $RLI_r$ is the real road-landslide index, and $\Sigma RL_i$ is the total length of road routes in the landslide area.

## 3. Results

In the area studied, landslides are mostly observed on agricultural land, in pyroclastic rock-andesite-basalt lithological units, at elevations of less than 750 m, on 15°–30° slopes, in west and northwest aspects (although landslide distributions have very close values in all aspects), at 0–150 m distances to streams, and at 0–200 m distances to roads. The results of the LR model applied in the present study are given in Table 3.

The results of the developed LR model showed that all parameters had positive effects on landslide occurrence

**Table 3.** The results of LR analysis.

| Name | Value | Name | Value |
|---|---|---|---|
| Intercept | −10.7967 | −2Log(L0) | 149905.4396 |
| Land use | 0.599764 | −2Log(L) | 111763.5921 |
| Slope | 0.460694 | Pseudo $R^2$ | 0.2544 |
| Aspect | 1.625798 | Goodness of fit | 414379.3280 |
| Lithology | 0.511397 | Chi square (8) | 38141.8474 |
| Elevation | 0.395534 | | |
| Distance to road | 0.914077 | | |
| Distance to stream | 1.033451 | | |
| Plan curvature | 1.158766 | | |

in the area. The pseudo $R^2$ statistic of the model was 0.2544. This was satisfactory, as a value greater than 0.2 shows a relatively good fit (Clark and Hosking, 1986). The AUC value of the model was 0.905, which is also in the satisfactory range (Yılmaz, 2009; Van Den Eeckhaut et al., 2010; Ercanoğlu and Temiz, 2011). According to the susceptibility map including 5 susceptibility classes (Figure 3), 8439.9 ha were located in the very low-susceptibility class, 20,191.7 ha in the low-susceptibility class, 14,211.6 ha in the moderate-susceptibility class, 6659.0 ha in the high-susceptibility class, and 371.8 ha in very high-susceptibility class areas.

The road network map overlaid with the landslide-susceptibility map is shown in Figure 4. The results of overlay analysis are given in Table 4. According to the overlay analysis results of the roads in the network plan, 84.1 km were located over the very low-susceptibility areas, 413.5 km over the low-susceptibility areas, 232.1 km over the moderate-susceptibility areas, 174.6 km over the high-susceptibility areas, and 22.7 km over the very high-susceptibility areas. Of those roads that have not yet been constructed, 25.2 km are to be located over very low-susceptibility areas, 29.5 km over low-susceptibility areas, 9.9 km over moderate-susceptibility areas, and 1 km over high-susceptibility areas. There are no planned roads over very high-susceptibility areas.

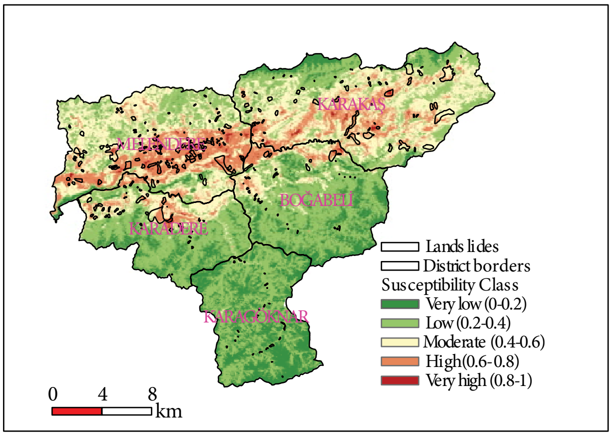

**Figure 3.** The landslide-susceptibility map generated and classified landslide-susceptibility map.

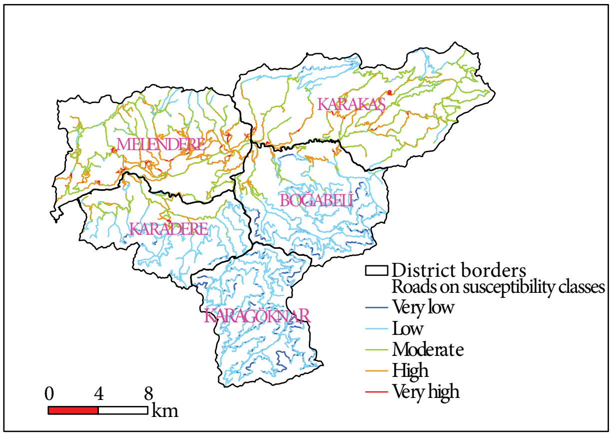

**Figure 4.** Road network map overlaid with landslide-susceptibility map.

Of all village roads in the area, 0.2 km were located over very low-susceptibility areas, 22 km over low-susceptibility areas, 106.6 km over moderate-susceptibility areas, 134.3 km over high-susceptibility areas, and 19.7 km over very high-susceptibility areas. Of all forest roads, 83.4 km were located over very low-susceptibility areas, 390.5 km over low-susceptibility areas, 112.2 km over moderate-susceptibility areas, 28 km over high-susceptibility areas, and 1.2 km over very high-susceptibility areas. Of all motorways, 1 km was located over low-susceptibility areas, 13.2 km were over moderate-susceptibility areas, 12.3 km over high-susceptibility areas, and 1.8 km over very high-susceptibility areas. No motorway was located over the very-low susceptibility areas. In terms of the road type, more village roads were located in high and very high susceptibility areas than forest roads and motorways. In addition, more of the forest roads were located in high and very high susceptibility areas than motorways.

In addition, in the present study a total of 157 landslides were identified on 370.2 km of road routes, and 37.9 km of roads remain directly in landslide areas. The distribution of landslide frequency values in the forest districts is given in Table 5. Real landslide frequency and general landslide frequency on the roads were 0.42 and 0.18, respectively. The distribution of road-landslide index values is given in Table 6. According to the real landslide frequency values, at least one landslide was seen in every 2.5 km of road routes, while general landslide frequency values showed 1 landslide in every 5 km among all roads. The real road-landslide index and the general road-landslide

**Table 4.** The results of overlay analysis.

| Forest district | Susceptibility class | The length of road types (km) and their percentage (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Village road | % | Forest road | % | Motorway | % |
| Boğabeli | Very low | 0.15 | 0.50 | 27.79 | 16.86 | 0.00 | 0.00 |
| | Low | 3.53 | 11.75 | 121.15 | 73.52 | 0.00 | 0.00 |
| | Moderate | 10.07 | 33.54 | 12.86 | 7.80 | 0.00 | 0.00 |
| | High | 14.79 | 49.26 | 2.81 | 2.81 | 0.00 | 0.00 |
| | Very high | 1.48 | 4.94 | 0.18 | 0.18 | 0.00 | 0.00 |
| Karadere | Very low | 0.05 | 0.17 | 6.71 | 6.38 | 0.00 | 0.00 |
| | Low | 3.80 | 13.07 | 79.12 | 75.22 | 0.00 | 0.00 |
| | Moderate | 13.12 | 45.10 | 14.15 | 13.45 | 0.00 | 0.00 |
| | High | 11.83 | 40.66 | 4.46 | 4.25 | 0.00 | 0.00 |
| | Very high | 0.29 | 1.00 | 0.75 | 0.71 | 0.00 | 0.00 |
| Karakaş | Very low | 0.00 | 0.00 | 2.45 | 1.82 | 0.00 | 0.00 |
| | Low | 4.39 | 6.11 | 46.36 | 34.55 | 0.00 | 0.00 |
| | Moderate | 28.65 | 39.85 | 68.21 | 50.85 | 0.00 | 0.00 |
| | High | 33.75 | 46.95 | 16.97 | 12.65 | 0.00 | 0.00 |
| | Very high | 5.10 | 7.09 | 0.16 | 0.12 | 0.00 | 0.00 |
| Karagöknar | Very low | 0.00 | 0.00 | 46.94 | 26.07 | 0.00 | 0.00 |
| | Low | 0.00 | 0.00 | 132.50 | 73.59 | 0.00 | 0.00 |
| | Moderate | 0.00 | 0.00 | 0.62 | 0.34 | 0.00 | 0.00 |
| | High | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Very high | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Melendere | Very low | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Low | 10.30 | 6.82 | 11.40 | 35.88 | 1.00 | 3.51 |
| | Moderate | 54.80 | 36.08 | 16.40 | 51.70 | 13.20 | 46.82 |
| | High | 73.90 | 48.68 | 3.80 | 11.87 | 12.30 | 43.44 |
| | Very high | 12.80 | 8.42 | 0.10 | 0.45 | 1.80 | 6.23 |

**Table 5.** Real and general landslide frequency values in the forest districts.

| Forest district | NL | RRL (km) | RL (km) | RLF | GLF |
|---|---|---|---|---|---|
| Boğabeli | 24 | 54.1 | 167.0 | 0.44 | 0.14 |
| Karadere | 20 | 47.5 | 130.6 | 0.42 | 0.15 |
| Karakaş | 29 | 100.3 | 195.2 | 0.29 | 0.15 |
| Karagöknar | 20 | 33.9 | 162.6 | 0.59 | 0.12 |
| Melendere | 64 | 134.4 | 207.9 | 0.48 | 0.31 |
| **Study area** | **157** | **370.2** | **866.3** | **0.42** | **0.18** |

**Table 6.** Real and general road-landslide index in the forest districts.

| Forest district | $RL_i$ (km) | RRL (km) | RL (km) | $RLI_r$ | $RLI_g$ |
|---|---|---|---|---|---|
| Boğabeli | 2.5 | 54.1 | 190.3 | 0.05 | 0.01 |
| Karadere | 7.5 | 47.5 | 137.6 | 0.16 | 0.06 |
| Karakaş | 1.4 | 100.3 | 205.7 | 0.01 | 0.01 |
| Karagöknar | 8.9 | 33.9 | 181.1 | 0.26 | 0.05 |
| Melendere | 17.6 | 134.4 | 214.1 | 0.13 | 0.08 |
| **Study area** | **37.9** | **370.2** | **931.9** | **0.10** | **0.04** |

index values in the area were 0.10 and 0.04, respectively. According to the real and general road-landslide index values, 10% of road routes were located in an area directly affected by at least 1 landslide, while 4% of all roads in the area were directly affected by landslides.

## 4. Discussion

Forest roads are important infrastructures that enable forestry activities. In traditional planning of road networks, road locations have been determined without taking into account environmental factors such as landslides. The recent development of GIS and computer technologies and their integration with statistical methods have made the quantitative assessment and mapping of landslides possible. Landslide-susceptibility maps have been widely generated for various purposes such as reducing the effects of landslides, decision making, and planning. In the present study, through assessment of forest road conditions in terms of landslide factors, landslide-susceptibility maps were generated using a GIS-based LR method. The goal was to investigate the use of a landslide-susceptibility map as a database for planning forest road networks.

The Yığılca Forest Directorate, located in the landslide-prone Western Black Sea Region of Turkey, was selected as the study area. It was observed during fieldwork that roads cause landslide events, and landslide-related damage on roadbeds results in maintenance costs. In addition, it was noted that some roads needed to be relocated due to a high risk of landslides. Road construction on high- and very high-susceptibility areas may require techniques as simple as a full bench end-haul or as complex as a large rock buttress keyed into the bedrock. Frequent inspections are important, particularly in these high- and very high-susceptibility areas with a history of landslides. In many instances road-related landslides cannot be economically stabilized. Ideally, the road could be relocated or kept open by altering the grade so as to conform to the landslide movement. Fill-slope should not be placed on any actively moving landslides, and runoff from roads should be routed away from these features and all other unstable slopes.

## References

Akgün A (2011). A comparison of landslide susceptibility maps produced by logistic regression, multi-criteria decision, and likelihood ratio methods: a case study at İzmir, Turkey. Landslides 9: 93–106.

Aleotti P, Chowdhury R (1999). Landslide hazard assessment: summary review and new perspectives. B Eng Geol Environ 58: 21–44.

Allison C, Sidle RC, Tait D (2004). Application of decision analysis to forest road deactivation in unstable terrain. Environ Manage 33: 173–185.

Arıcak B, Enez K, Acar HH (2010). Defining the Slope Stability Areas of Forest Roads. FORMEC 2010, Forest Engineering: Meeting the Needs of the Society and the Environment, CD Proceeding, Padua, Italy.

Ayalew L, Yamasgishi H (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan. Geomorpholgy 65: 15–31.

Bai SB, Wang J, Zhang FY, Pozdnoukhov A, Kanevski M (2008). Prediction of landslide susceptibility using logistic regression: a case study in Bailongjiang River Basin, China. Fifth International Conference on Fuzzy Systems and Knowledge Discovery, pp. 647–651.

Clark WA, Hosking PL (1986). Statistical Methods for Geographers (Chapter 13). New York, NY, USA: Wiley.

Coker RI, Fahey BD (1993). Road-related mass movement in weathered granite, Golden Downs and Motueka Forests, New Zealand: a note. J Hydrol 31: 65–69.

Dhakal AS, Sidle RC (2003). Long-term modelling of landslides for different forest management practices. Earth Surf Proc Land 28: 853–868.

Duman TY, Çan T, Emre Ö, Keçer M, Doğan A, Ateş Ş, Durmaz S (2005). Landslide inventory of northwestern Anatolia, Turkey. Eng Geol 77: 99–114.

Ercanoğlu M, Gökceoğlu C (2002). Assessment of landslide susceptibility for a landslide-prone area (north of Yenice, NW Turkey) by fuzzy approach. Environ Geol 41: 720–730.

Ercanoğlu M, Temiz FA (2011). Application of logistic regression and fuzzy operators to landslide susceptibility assessment in Azdavay (Kastamonu, Turkey). Environ Earth Sci 64: 949–964.

Erener A, Düzgün HSB (2010). Improvement of statistical landslide susceptibility mapping by using spatial and global regression methods in the case of More and Romsdal (Norway). Landslides 7: 55–68.

Girvetz E, Shilling F (2003). Decision support for road system analysis and modification on the Tahoe National Forest. Environ Manage 32: 218–233.

Görcelioğlu E (2004). Orman Yolları-Erozyon İlişkisi. İ.Ü. İstanbul: Orman Fakültesi Yayınları No.: 4460/476, 184 s.

Gümüş S, Acar HH, Toksoy D (2008). Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. Environ Monit Assess 142: 109–116.

Hasmadi MI, Kamaruzaman J, Azizon JM (2008). Forest road assessment in Ulu Muda Forest Reserve, Kedah, Malaysia. Modern App Sci 2: 100–108.

Heam G, Hunt T, Aubert J, Howell J (2007). Landslide impacts on the road network of Lao PDR and the feasibility of implementing a slope management programme. DFID/SEACAP-funded project.

Hosmer DW, Lemeshow S (2000). Applied Logistic Regression. Wiley Series in Probability and Statistics, Second Edition, New York, NY, USA: Wiley.

Hosseini SA, Mazrae MR, Lotfalian M, Parshakhoo A (2012). Designing an optimal road network by consideration of environmental impacts in GIS. J Environ Eng Landsc 20: 58–66.

Jakob M (2000). The impacts of logging on landslide activity at Clayoquot Sound, British Columbia. Catena 38: 279–300.

Jones JA, Swanson FJ, Wemple BC, Snyder KU (2000). Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conserv Biol 14: 76–85.

Kıncal C, Akgün A, Koca MY (2009). Landslide susceptibility assessment in the İzmir (West Anatolia, Turkey) city center and its near vicinity by the logistic regression method. Environ Earth Sci 59: 745–756.

Lee S (2005). Application of logistic regression model and its validation for landslide susceptibility mapping using GIS and remote sensing data. Int J Remote Sens 26: 1477–1491.

Lee S, Talib JA (2005). Probabilistic landslide susceptibility and factor effect analysis. Environ Geol 47: 982–990.

Malamud BD, Turcotte DL, Guzetti F, Reichenbach P (2004). Landslide inventories and their statistical properties. Earth Surf Proc Land 29: 687–711.

Marschalko M, Treslin L (2009). Impact of underground mining to slope deformation genesis at Doubrava Ujala. Acta Montanistica Slovaca 14: 232–240.

Nefeslioğlu HA, Gökçeoğlu C, Sönmez H (2008). An assessment on the use of logistic regression and artificial neural networks with different sampling strategies for the preparation of landslide susceptibility maps. Eng Geol 97: 171–191.

Radfar I, Zolfani SH, Rezaciniya N, Shadifar M (2011). Using AHP-COPRAS-G method for forest road locating. In: Second IEEE International Conference on Emergency Management and Management Sciences (ICEMMS), Beijing, pp. 547–550.

Reichenbach P, Ardizzone F, Cardinali M, Galli, M, Guzetti F, Salvati P (2002). Landslide events and their impact on the transportation network in the Umbria region, central Italy. Proceedings of the 4th EGS Plinius Conference held at Mallorca, Spain.

Sharpe CFS (1938). Landslides and Related Phenomena. New York, NY, USA: Columbia University Press.

Sidle RC, Pierce AJ, O'Loughlin CL (1985). Hillslope Stability and Land Use. Water Resources Monograph Series, Volume 11. Washington, DC: American Geophysical Union.

Sorkhi A, Hosseini SA, Lotfalian M, Parsakhoo A (2012). Effect of the standard clearing limit of forest road right-of-way on stand stock growth: case study of Vaston forests, Hyrcanian zone. Afr J Environ Sci Tech 6: 43–49.

Süzen ML, Kaya BŞ (2011). Evaluation of environmental parameters in logistic regression models for landslide susceptibility mapping. Int J Digit Earth 5: 1–18.

Swanson FJ, Dyrness CT (1975). Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3: 393–396.

Vahidnia MH, Alesheikh AA, Alimohammadi A, Hosseinali F (2010). A GIS-based neuro-fuzzy procedure for integrating knowledge and data in landslide susceptibility mapping. Comput Geosci 36: 1101–1114.

Van Den Eeckhaut M, Marre A, Poessen J (2010). Comparison of two landslide susceptibility assessments in the Champagne–Ardenne region (France). Geomorphology 115: 141–155.

Wachal DJ, Hudak PF (2000). Mapping landslide susceptibility in Travis County Texas USA. GeoJournal 51: 245–253.

Wemple BC, Swanson FJ, Jones JA (2001). Forest roads and geomorphic process interactions, Cascade Range, Oregon. Earth Surf Proc Land 26: 191–204.

Yılmaz I (2009). Landslide susceptibility MAPPING using frequency ratio, logistic regression, artificial neural networks and their comparison: a case study from Kat landslides (Tokat–Turkey). Comput Geosci 35: 1125–1138.