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Landslide Susceptibility Assessment of Forest Roads*

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Abstract

In last few decades, there has been an increasing interest in using Landslide Susceptibility Maps (LSMs) especially in planning and decision making stages of landslide prevention and mitigation activities, as well as in landslide related studies. In forested areas, inappropriately located roads potentially cause slope instability problems such as landslides which then result in serious destructions on road networks and deformations on road platforms. Thus, one of the further usages of LSM may involve overlapping analysis with forest roads in order to obtain information about how road networks should be planned and located considering land sliding potential. Statistical approaches such as Logistic Regression (LR) method are well integrated with GIS based evaluation of landslide probability of slopes in larger regions. In this study, LSMs of two forest districts (Gölyaka and Kardüz) in Gölyaka Forest Directorate (Düzce, Turkey) was generated by using LR method based on an inventory of 52 landslides and eight conditioning parameters. These parameters include elevation, slope, land-use, lithology, aspect, distance to faults, distance to streams, and distance to roads. For overlapping analysis, forest road layer was obtained from Bolu Regional Directorate of Forestry (RDF) in vector data format. It was found that landslide susceptibilities obtained in study area were between 0 and 0.57 with 0.85 AUC (Area Under the Curve) value. The results indicated that all of the selected parameters had positive effects on landslide occurrences. After normalization of generated susceptibility values between 0 and 1, LSM was classified into following five classes: very low (0-0.2), low (0.2-0.4), moderate (0.4-0.6), high (0.6-0.8), and very high (0.8-1.0). Then, classified LSM was overlapped with forest road layer which includes the total of 380.8 km road. According to classified susceptibility map, more than 95% of total area is located in very low and low susceptibility classes, 3% of the area has moderate landslide susceptibility, while remains have high and very high susceptibilities. According to overlapping analysis, 1.3 km of roads is located within very high susceptibility and 5.1 km of roads is located within high susceptibility classes. The rest of the roads (i.e. more than 95%) are located in other susceptibility classes.

Keywords: Forest roads, Landslide Susceptibility Maps, Logistic Regression

1. Introduction

Landslide susceptibility assessment has become an important subject for earth scientists, engineers, planners, and decision makers (Ercanoğlu and Gökçeoğlu, 2002). For estimating the likelihood in landslide occurrence, Landslide Susceptibility Maps (LSMs) were widely used considering spatial correlations between important terrain characteristics and the past landslide distribution, often applying Geographical Information System (GIS) based techniques (Vahidnia et al., 2010). Landslide susceptibility mapping techniques can be divided into four classes such as: i) heuristic, ii) deterministic, iii) statistical, and iv) landslide inventory based probability (Akgün, 2011). Logistic Regression (LR) method, a statistical approach, 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, Eker and Aydın, 2014). LR is employed to analyze the relationship between the categorical or binary response variable and one or more categorical or binary explanatory variables (Bai et al., 2008).

LSMs were generally generated by many researchers for assessment/mapping of landslide susceptibilities of a region in the literature. Related

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studies evolved from introducing used methods in initial studies to comparing the performance of different approaches. For instance, Ercanoğlu and Temiz (2011) evaluated landslide susceptibility in Azdavay (Kastamonu, Turkey) by using two quantitative methods: LR and fuzzy operators. They considered six input parameters such as topographical elevation, lithology, land use, slope, aspect and distance to streams to perform landslide susceptibility analyses based on an inventory of 96 landslides. In total, 18 landslide susceptibility maps were produced by LR and fuzzy operators in a GIS environment and the methods applied were compared.

Previous studies highlighted that LSMs can be used in planning and decision making stages of landslide prevention and mitigation activities, as well as in landslide related studies. However, there is very limited study made for evaluating forest roads in terms landslide susceptibilities. For the first time, Eker and Aydın (2014) evaluated forest road conditions in terms of landslide susceptibilities. They generated LSM in Yığılca Forest Directorate (Turkey) by using LR method. They selected eight landslide conditioning parameters based on field works and an inventory of 288 landslides.

The evaluating forest roads conditions in terms of landslide susceptibilities is important since selecting inappropriate road locations in forested areas result in adverse impacts on the natural environment in conjunction with the occurrence of technical and economic problems (Görcelioğlu, 2004). Especially forest roads with stability problems trigger landslide hazards which then lead to costly road maintenance and reconstruction works. The occurrence of landslides can make roads unusable because the material displacement can block roads, damage road components, and destroy roadbeds.

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). In areas with high landslide risk, determining the road location is the most difficult stage of road network planning. That's why, landslides have to be taken into account in forest road planning, particularly in mountainous regions where road construction causes increased slope stability problems and higher road maintenance costs. However, many forest engineers still use traditional methods (Hosseini et al., 2012) that are able to consider landslide impact in determining road locations. Therefore, LSMs can be used in order to provide accurate information about how to locate suitable forest roads considering land sliding potential (Eker and Aydın, 2014).

In present study, LSMs of two forest districts (Gölyaka and Kardüz) in Gölyaka Forest Directorate (Düzce, Turkey) was generated using LR method based on landslide data and selected conditioning parameters. Then, an overlapping analysis was performed using the forest road network and the landslide susceptibility map to determine the distribution of roads with respect to susceptibility classes and to evaluate them in terms of landslides.

2. Material and Methods

2.1. Study Area and Data Description

Gölyaka and Kardüz forest districts, located in Gölyaka Forest Directorate in the city of Düzce in Turkey were selected as study area (Figure 1). These forest districts are located in Black Sea Region of Turkey, where landslides incidents are very common. The top, left, right, and bottom coordinates of the study area are 4521007, 320760, 336020, and 4503527 m in ED 1950 UTM Zone 36, respectively. Gölyaka and Kardüz forest districts cover the area of 9128.13 ha and 5098.12 ha, respectively.

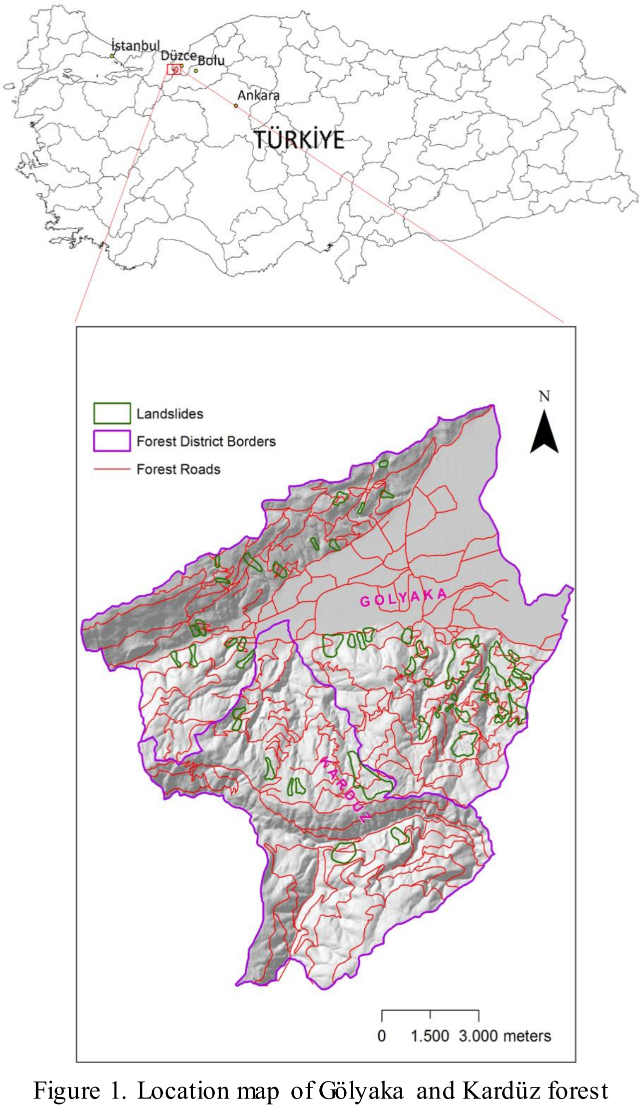


Figure 1. Location map of Gölyaka and Kardüz forest districts and Forest road network

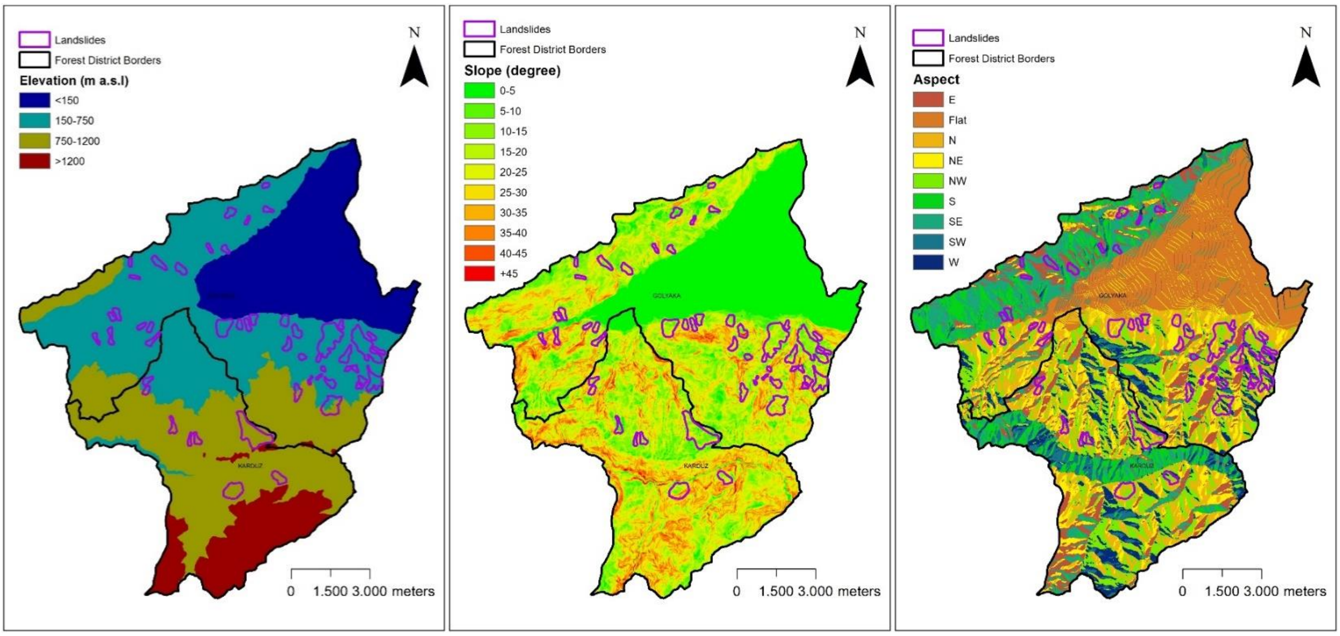
Forest road network data was obtained from Bolu Regional Directorate of Forestry (RDF) in vector data format. According to this dataset, 380.8 km forest roads are located in the selected two forest districts. Gölyaka forest district has 242.42 km forest roads, while Kardüz forest district has 138.38 km forest roads. An inventory of 52 landslides was generated through fieldwork as well as inventory data obtained from the General Directorate of Mineral Research and Exploration (MRE) in Turkey. According to landslide inventory in the area, Gölyaka forest district has 44 landslides, while Kardüz forest district has 8 landslide incidences. In the study, lithology and fault data was obtained from General Directorate of MRE in vector data format. Digital Elevation Model (DEM), used to derivate elevation, slope, and aspect data, was generated from 1/25000 topographical maps. In addition, stream layer was produced based on 1/25000 topographic maps. Land-use data was derived from forest stand data obtained from Bolu RDF. GIS methods and techniques were implemented by using ArcGIS 10.1.

2.2. Landslide Susceptibility Mapping with Logistic Regression

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). Based on the observations in the field studies, following landslide conditioning parameters (i.e. set of explanatory variables) were selected for the landslide-susceptibility mapping; elevation, slope, aspect, land-use, lithology, distance to faults, distance to streams, and distance to roads (Figure 2, Figure 3). 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.

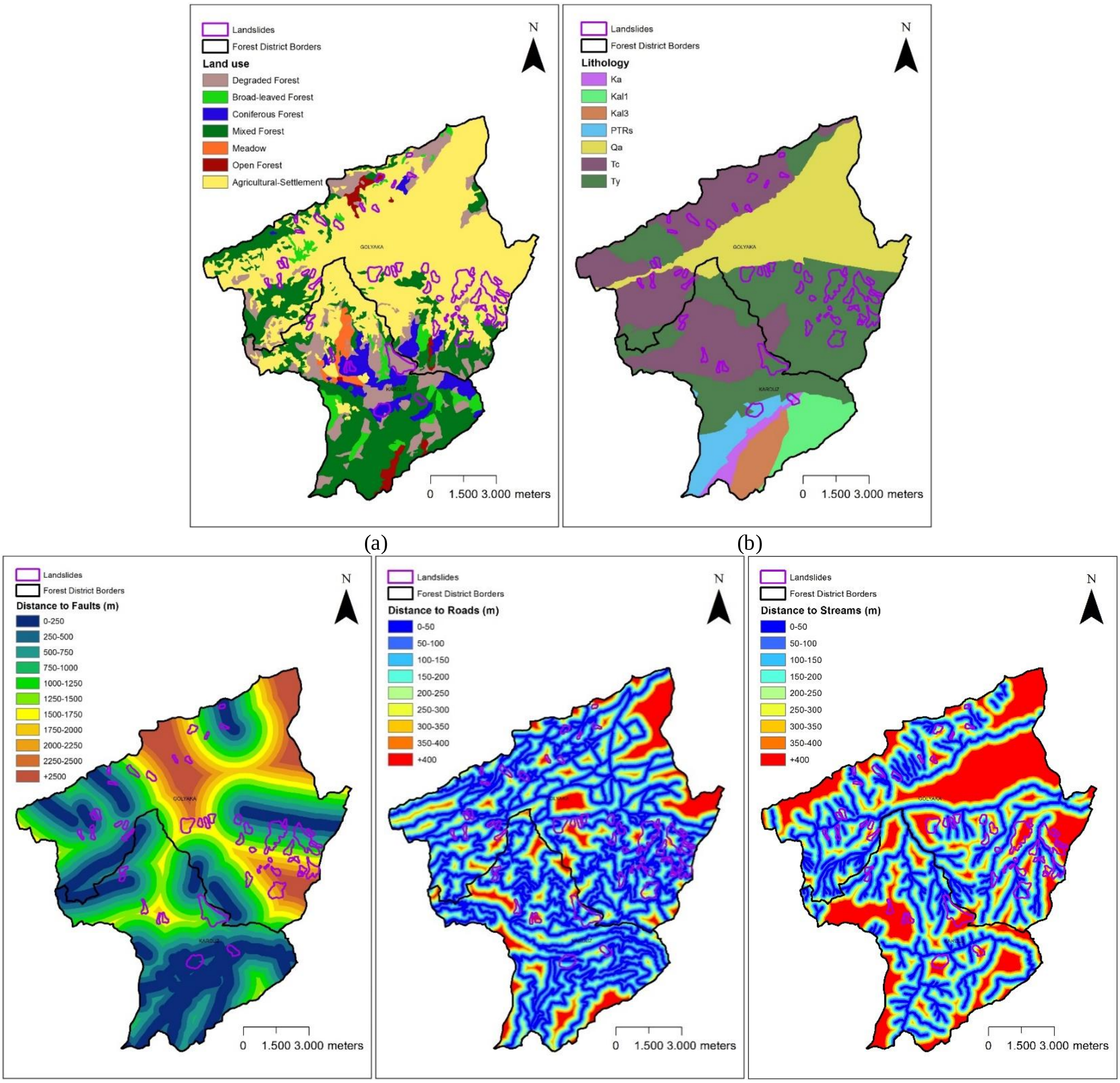
The LR model was performed with 10% stratified random sampling procedure. Then, the landslide-susceptibility map generated with LR was divided into five susceptibility classes including very low susceptibility (0–0.2), low susceptibility (0.2–0.4), moderate susceptibility (0.4–0.6), high susceptibility (0.6–0.8), and very high susceptibility (0.8–1.0), following normalization of generated susceptibility values between 0 and 1. However, before the LR model was performed, the parameter maps were classified, and the number of pixels in each class was calculated. Following this process, frequency ratio (FR) of all classes was calculated by constructing a table for each parameter map, as stated by Lee and Talib (2005). LR analysis was carried out by using calculated FR values assigned to each class of each parameter map. Further information about this methodology can be found in Eker and Aydın (2014).

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 purpose (Eker and Aydın, 2014).



(a) (b) (c)

Figure 2. Landslide conditioning parameters used in LR: a) elevation, b) slope, c) aspect



(c) (d) (e)

Figure 3. Other landslide conditioning parameters used in LR: a) Land use, b) lithology (Qa: alluvion, PTRs: marble, Ka: metasandstone-metaclaystone-metapelitic, Kal1: serpantinite, Kal3: gabbro, Tc: sandstone-mudstone, Ty: pyroclastic rocks-andesite-basaltic) c) Distance to faults d) Distance to roads e) Distance to streams

2.3. Landslide Susceptibility of Forest Roads

After successfully finding best fitting model, i.e. generating LSM, an overlapping analysis was carried out using forest road network data, in order to evaluate forest road conditions in terms of landslide susceptibility. Because the output LSM of LR analysis made via LOGISTIREC module is in raster format, it was necessary to convert the classified LSM to polygon vector format for conditioning it to overlap with the road network. The whole process of evaluating forest roads conditions in terms of landslide susceptibilities is given in Figure 4.

3. Results and Discussion

According to results, all parameters selected for LR analysis has positive effect on landslide occurrences (Table 1). The AUC value of the model was 0.849, which is also in the satisfactory range comparing with the previous studies (Yılmaz, 2009; Van Den Eeckhaut et al., 2010; Ercanoğlu and Temiz, 2011). AUC value indicates a perfect fit when it is equal to 1, and indicates a random fit when it is equal to 0.5 (Begueria, 2006). Yılmaz (2009) generated LSMs by using Frequency Ratio (FR), LR, and Artificial Neural Networks (ANN) methods. They obtained AUC values as 0.826 for FR, 0.842 for LR, and 0.852 for ANN methods. Van Den Eeckhaut et al. (2010) generated LSM by using LR and obtained AUC value as 0.888. Eker and Aydın (2014) obtained AUC value as 0.905 by using LR method. Raw LSM before classification procedure and classified LSM are given in Figure 5.

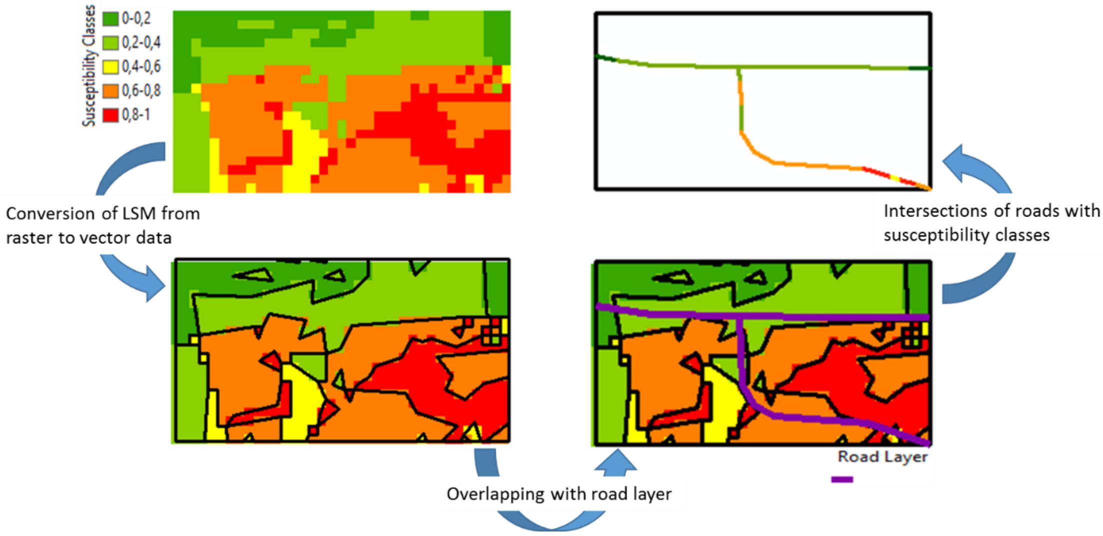


Figure 4. The process of evaluation of forest roads conditions in terms of landslide susceptibility

Table 1. Obtained coefficients of variables in LR model

Variables	Coefficient
Intercept	-10.447
Slope	0.686
Lithology	0.667
Land-use	0.918
Elevation	0.810
Distance to Streams	0.728
Distance to Roads	0.641
Aspect	0.857
Distance to Faults	0.974

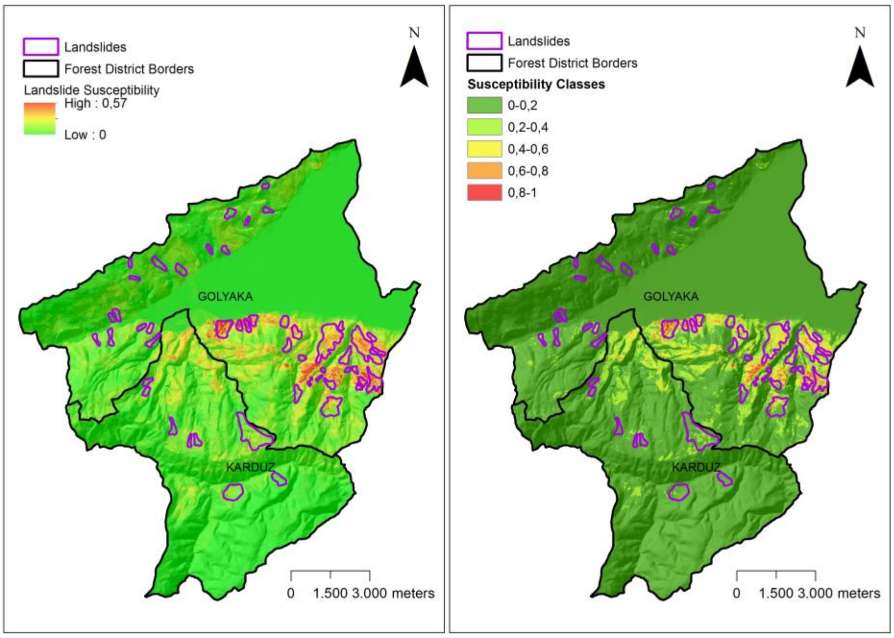


Figure 5. Raw LSM (left) and classified LSM (right)

In addition, the distribution percentage of landslide susceptibility classes located in landslides was calculated. According to this, %75.7 of all pixels in very high and high susceptibility classes (corresponds to %1 of all susceptibility classes) is located in landslides, while remaining susceptibility classes are located in landslides. However, this corresponds to %8.2 of all pixels located in landslides (Figure 6).

Landslide susceptibilities in raw LSM vary between 0 and 0.57 depending on the selected parameters. According to classified LSM, more than 95% of total area (13638.76 ha) is located in very low and low susceptibility classes, only 1% of total area (143.51 ha) is located in very high and high susceptibility classes, while remain is located in moderate susceptibility class. Table 2 summaries the distribution of susceptibility classes in the study area.

Forest road network map overlapped with classified LSM is given in Figure 7. This map represents intersections of forest roads with susceptibility classes. According to overlapping analysis, 1.3 km of roads is located in very high susceptibility, 5.1 km of roads is located in high susceptibility classes. Remains (more than 95% of all roads) are located in other susceptibility classes. Table 3 summaries the distribution of roads over the susceptibility classes. Eker and Aydın (2014) made similar study (Yığılca Forest Directorate) in which the results are compared, Yığılca region is more susceptible to land sliding than Kardüz and Gölyaka, and selected conditioning parameters and their frequency ratios are not the same with study made by Eker and Aydın (2014). In the present study, distance to faults was used rather than curvature parameter used by Eker and Aydın (2014). It must keep in mind that landslide susceptibility mapping is sensitive to selected method and selected conditioning parameters (Erener and Duzgun, 2011). Also road density in Yığılca region is higher than road density in Kardüz and Gölyaka regions.

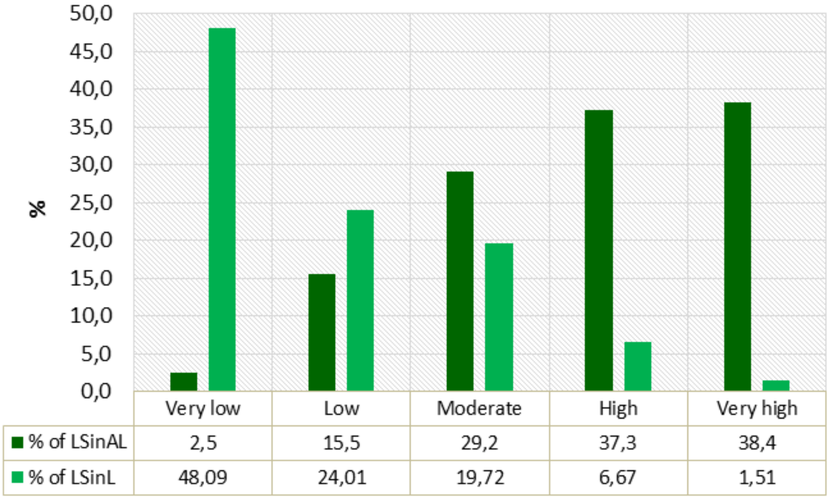


Figure 6. The distribution percentage of susceptibility classes in landslides (LSinAL: Distribution of landslide susceptibility classes in landslides according to all susceptibility classes, LSinL: Distribution of each landslide susceptibility classes in landslides)

Table 2. Distribution of susceptibility classes

Susceptibility Classes	Area (ha)	Percentage (%)
Very High (0.8-1.0)	25.88	0.18
High (0.6-0.8)	117.63	0.83
Moderate (0.4-0.6)	443.98	3.12
Low (0.2-0.4)	1017.06	7.15
Very low (0-0.2)	12621.70	88.72

Table 3. Distribution of roads in susceptibility classes

Susceptibility Classes	Road Length (km)	Percentage (%)
Very High (0.8-1.0)	1.27	0.33
High (0.6-0.8)	5.05	1.33
Moderate (0.4-0.6)	16.74	4.40
Low (0.2-0.4)	33.74	8.86
Very low (0-0.2)	324.00	85.08

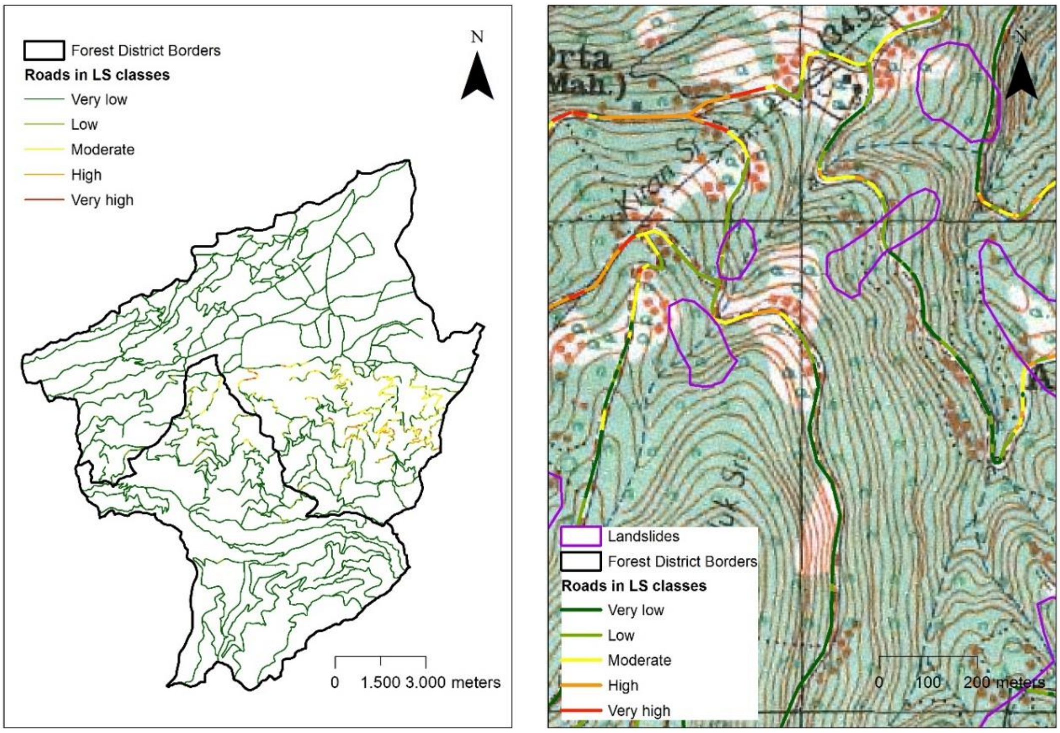


Figure 7. Forest roads overlapped with landslide susceptibility classes (left) and roads in susceptibility classes and landslide occurrences in inventory (right)

Overlapping forest road network with landslide susceptibility provides information about how planned road routes are located in terms of land sliding potential. That's why, forest road planners can be use LSMs in determination of suitable road routes. In addition, this data can help making decision in determination of necessity of counter-measures against the sliding. On the other hand, the results obtained from such models should be verified in the field since there are several factors, which play important role on the degree of roads suffering from landslides such as the type and state of activity of landslide, the location of the roads, and the geomorphology of the area. For instance, as depicted in Figure 6, some roads can be located in low or very low susceptibility class, even they are located in landslide area. Nevertheless, this data will provide useful brief information on landslide susceptibility and road interactions.

4. Conclusions

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. In the present study, the aim was to show the use of a landslide-susceptibility map as a database for planning forest road networks. For the assessment of forest road conditions in terms of landslide susceptibilities, LSM was generated using a GIS-based LR method. LR based susceptibility map was created with a satisfactory validity. Eight conditioning parameters were used by computing FR values for each class of each parameter. Even though obtained overlapping results should be checked in the field, because there are several factors, which affect the degree of suffering roads from landslide such as the type and state of activity of landslide, the location of the roads, and the geomorphology of the area, this overlapping analysis will provide useful brief information on landslide susceptibility and road interactions.

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