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Fuzzy rule-based landslide susceptibility mapping in Yığılca Forest District (Northwest of Turkey)

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Abstract*:* Landslide susceptibility map of Yığılca Forest District was formed based on developed fuzzy rules using GIS-based FuzzyCell software. An inventory of 315 landslides was updated through fieldworks after inventory map previously generated by the authors. Based on the landslide susceptibility mapping study previously made in the same area, for the comparison of two maps, same 8 landslide conditioning parameters were selected and then fuzzified for the landslide susceptibility mapping: land use, lithology, elevation, slope, aspect, distance to streams, distance to roads, and plan curvature. Mamdani model was selected as fuzzy inference system. After fuzzy rules definition, Center of Area (COA) was selected as defuzzification method in model. The output of developed model was normalized between 0 and 1, and then divided five classes such as very low, low, moderate, high, and very high. According to developed model based 8 conditioning parameters, landslide susceptibility in Yığılca Forest District varies between 32 and 67 (in range of 0-100) with 0.703 Area Under the Curve (AUC) value. According to classified landslide susceptibility map, in Yığılca Forest District, 32.89% of the total area has high and very high susceptibility while 29.59% of the area has low and very low susceptibility and the rest located in moderate susceptibility. The result of developed fuzzy rule based model compared with previously generated landslide map with logistic regression (LR). According to comparison of the results of two studies, higher differences exist in terms of AUC value and dispersion of susceptibility classes. This is because fuzzy rule based model completely depends on how parameters are classified and fuzzified and also depends on how truly the expert composed the rules. Even so, GIS-based fuzzy applications provide very valuable facilities for reasoning, which makes it possible to take into account inaccuracies and uncertainties.

Keywords: FIS, FuzzyCell, GIS, landslide susceptibility mapping, Yığılca

Yığılca Orman İşletmesi'nde (Kuzeybatı Türkiye) bulanık-kural tabanlı heyelan duyarlılık haritasının oluşturulması

Özet: Yığılca Orman İşletmesinin heyelan duyarlılık haritası CBS-tabanlı FuzzyCell yazılımı kullanılarak bulanık kural tabanlı olarak oluşturulmuştur. 315 adet heyelan içeren envanter haritası alanda daha önce yazarlar tarafından üretilen envanterin arazi çalışmaları ile güncellenmiş şeklidir. Alanda daha önce yazarlar tarafından üretilen heyelan duyarlılık haritasına bağlı olarak karşılaştırma yapabilmek amacıyla, yine 8 adet parametre harita seçilmiş ve daha sonra heyelan duyarlılık haritalama için bulanıklaştırılmıştır: arazi kullanımı, litoloji, yükselti, eğim, bakı, yola uzaklık, dereye uzaklık ve plan eğrisellik. Bulanık çıkarım sistemi olarak Mamdani modeli seçilmiştir. Bulanık kuralların tanımlanmasından sonra modelin durulaştırması için Alan Merkezi metodu uygulanmıştır. Daha sonra elde edilen bulanık duyarlılık haritası 0-1 aralığında normalleştirilmiş ve çok düşük, düşük, orta, yüksek ve çok yüksek olmak üzere beş farklı duyarlılık sınıfına ayrılmıştır. Seçilen 8 parametre haritasına bağlı olarak geliştirilen modele göre, Yığılca Orman İşletmesinde heyelan duyarlılığı 0.703 EAA (Eğri Altındaki Alan) değeri ile 32 ila 67 (ki 1-100 aralığındadır) duyarlılıkları arasında belirlenmiştir. Sınıflandırılan heyelan duyarlılık haritasına göre Yığılca Orman İşletmesinin %32.84'ü yüksek ve çok yüksek duyarlılık sınıflarında iken, alanın %29.59'u düşük ve çok düşük duyarlılık sınıflarında, geriye kalan ise orta duyarlılık sınıfında yer almaktadır. Alanda daha önce lojistik regresyon (LR) metodu ile üretilen heyelan duyarlılık haritası ile karşılaştırıldığında duyarlılık sınıflarının dağılımında önemli farklılık gözlenmektedir. Bu bulanık kural tabanlı modelin tamamıyla parametrelerin nasıl sınıflandırıldığı ve bulanıklaştırıldığının yanı sıra kural tabanın ne kadar doğru oluşturulduğuna bağlıdır. Ancak yine de bulanık kural tabanı ile modelleme CBS entegre çalışmalarda oldukça esnek muhakeme imkanı ve böylece belirlilik ve kesinlik olmaması durumunun da dikkate alınmasına imkan sağlamaktadır.

Anahtar Kelimeler: FIS, FuzzyCell, CBS, heyelan duyarlılık haritalama, Yığılca

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1. INTRODUCTION

Among the natural hazards, landslides have significant responsibility of loss of life, injury, and property damage in mountains with steep slopes around the world. Landslides also shape landforms and deliver sediment and wood to the streams. Landslides are accepted as natural phenomenon unless they interact with human-being and properties. A landslide occurs when part of a slope material is unable to support its own weight. In other words, a landslide occurs when forces driving instability are greater than forces promoting slope stability (Conforth, 2005). Although landslides usually occur at steep slopes, they may also occur in areas with low relief or slope gradient. As many part of the world, in Turkey, due to its geological, topographical, and climatic characteristics, landslides are most frequent events which are responsible for crucial casualties and economic losses. Especially, Black Sea Region of Turkey is prone to landslide occurrence throughout active fault zones (Gökçe et al. 2008). That's why landslide hazard assessment for regional scale has become important in recent years. Hazard mapping should include spatial and temporal probability information of landslide occurrence for a region. However it seems that is not possible in Turkey due to fact that landslide records don't include necessary information. As a consequence of this situation, risk mapping of landslide is actually impossible. Hence landslide susceptibility mapping have been the most common approach in the evaluation of landslide prone areas for regional scales.

Landslide susceptibility assessment is an approach for estimating the likelihood in landslide occurrence considering spatial correlations between important terrain characteristics and the past landslide distribution (Vahidnia et al. 2010). The "susceptibility" term refers likelihood of landslide occurrence when leaving triggering variables out of assessment (Dai et al. 2002). Thus, particularly in the last two decades, it has become an important subject for earth scientists, engineers, planners, and decision makers (Ercanoğlu and Gökçeoğlu, 2002). In addition, due to developing Geographical Information System (GIS) and integrated methodologies, landslide susceptibility mapping has been a widely used method in landslide assessment studies. Since the early 1970s, many scientists have attempted to produce susceptibility maps, often applying GIS-based techniques (Vahidnia et al., 2010). Methods of landslide assessment have been classified into two approaches: qualitative and quantitative (Aleotti and Chowdhury, 1999). In addition, landslide susceptibility mapping which is sensitive to selected method (Erener and Duzgun, 2011) is divided into four classes such as: i) heuristic, ii) deterministic, iii) statistical, iv) landslide inventory based probability (Akgün. 2012). However, there is not a general agreement on which method is the best. But in terms of procedure in susceptibility mapping, certain steps are used: i) mapping past landslide in the relevant region, ii) selecting and mapping a set of conditioning (e.g. geological and geomorphological) factors that are supposed to be directly or indirectly correlated with landslide occurrence, iii) estimating the correlations of selected factors with landslide occurrence, and iv) determination of different landslide susceptibilities for the resulting mapping.

The heuristic methods are based on expert opinion in order for determination of landslide prone areas producing landslide susceptibility maps for large areas. Fuzzy logic approach, one of the heuristic approaches, is also used for mapping landslide susceptibility (Vahidnia et al. 2010; Ercanoğlu and Temiz, 2011; Gorsevksi et al. 2006; Pradhan, 2010; Tangestani, 2009). Fuzzy logic, introduced by Lotfi A. Zadeh in 1965, is generalization of classical logic. The difference of fuzzy logic from crisp (i.e., classical) is established by introducing a membership function. Different fuzzy models have been developed and two well-known are Mamdani and Tagaki-Sugeno (T-S) fuzzy models (Chai et al., 2009). Mamdani fuzzy model which has widespread acceptance is an important technique because it is intuitive and well-suited to human cognition (Chai et al., 2009). A Mamdani fuzzy model consist, for example, of the fuzzy rules such as "If X is A, Then Y is B". Mamdani type fuzzy rules defines a linguistic model. Mamdani fuzzy model has been used in landslide susceptibility mapping (Pourghasemi et al., 2012; Akgün et al., 2012; Osna et al., 2014). Fuzzy models are capable of incorporating knowledge from human experts naturally and conveniently, while traditional models fail to do so (Jang, 1993). Also fuzzy models have the ability to handle nonlinearity and interpretability feature of the models (Jang, 1993). Fuzzy models can be created by translating knowledge of experts to linguistic information as fuzzy rules, albeit there is no standard method available for transforming expert's knowledge (Yanar and Akyürek, 2006).

The Yığılca Forest District is located in the landslide-prone Western Black Sea Region of Turkey and suffers from landslides. Landslides in the region cause important damages over the roads as well as settlement and agricultural lands where hazelnut gardens are common. Hence, generation of landslide inventory and first of mapping landslide susceptibility is previously made by the authors using logistic regression model and published as Eker and Aydın (2014). In Yığılca Forest District, 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 (Eker and Aydın, 2014). Hence, in the present study, inventory map of landslide was updated by field works following previous study. In addition, landslide susceptibility map of Yığılca Forest District was formed based on developed fuzzy rules using GIS-based FuzzyCell software. Fuzzy inference system used in model is Mamdani Model. Then the results of applied model was compared with previous landslide susceptibility map generated.

2. MATERIAL AND METHODS

2.1. Study Area

The Yığılca Forest District was selected as the study area because it is located in the landslide-prone Western Black Sea Region of Turkey (Figure / Şekil 1). 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). A landslide inventory made previously by the authors (of the present study) in 2012 was updated by means of fieldworks in the area. Landslide locations were defined using a hand-held GPS (Global Positioning System) device and were traced to scale at 1/25000 on topographical maps, which were then digitized at the office-work stage. Total number of landslides in inventory map increased from 288 to 315 by adding 27 new landslide to database. In the study area, three types of landslide are observed: rotational slide, translational slide, and flow. An image of updated landslide event to database in the area is given in Figure / Şekil 2. The area is located very close to North Anatolian Fault Zone and also the region is mountainous with annual average precipitation is 1263 mm (Eker, 2013). But unfortunately, there is no information about what triggering factor is dominant. Even so, depending on observations in the fieldworks, it could be supposed that the landslides in the area are mainly triggered by heavy rain because the study area has slightly mountainous morphologic features and receives heavy precipitation frequently.

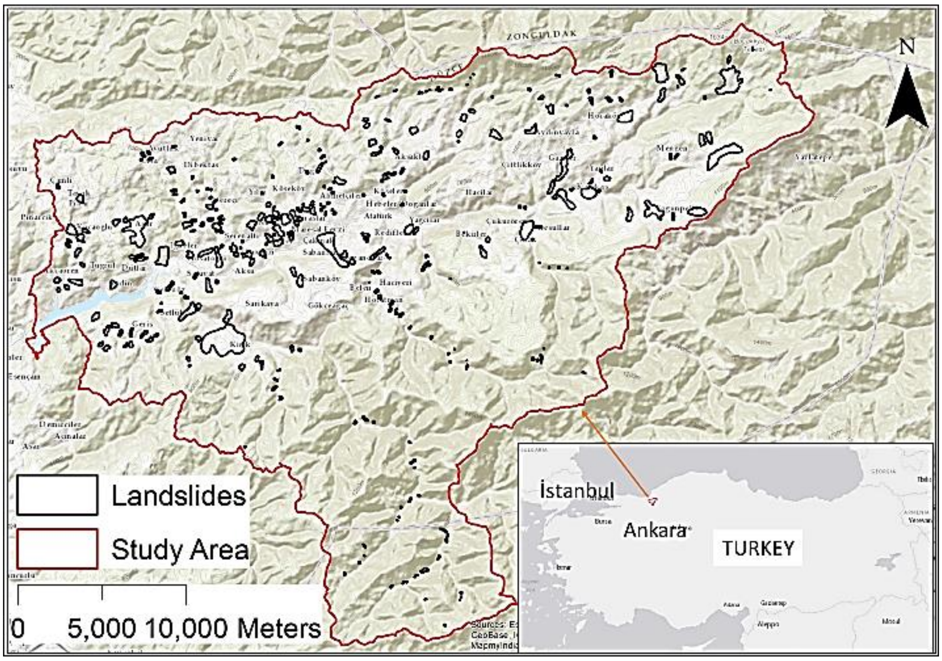


Figure 1. Location map of the study area

Şekil 1. Çalışma alanının konum haritası

Figure 2. Two different landslides failed in the region
Şekil 2. Bölgede oluşan iki farklı heyelan

2.2. Fuzzy Rule-based Landslide Susceptibility Mapping by Using GIS

The workflow of applied methodology is given in Figure / Şekil 3. Fuzzy rule-based landslide susceptibility map was generated by using FuzzyCell software developed by Yanar and Akyürek (2006). FuzzyCell is a system designed and implemented to enhance conventional GIS software (ArcMap®) with fuzzy set theory. FuzzyCell allows the users to incorporate human knowledge and experience in the form of linguistically defined variables into GIS-based spatial analyses. Further information about FuzzyCell is defined by Yanar and Akyürek (2006). The graphical user interface of FuzzyCell is depicted in Figure / Şekil 4.

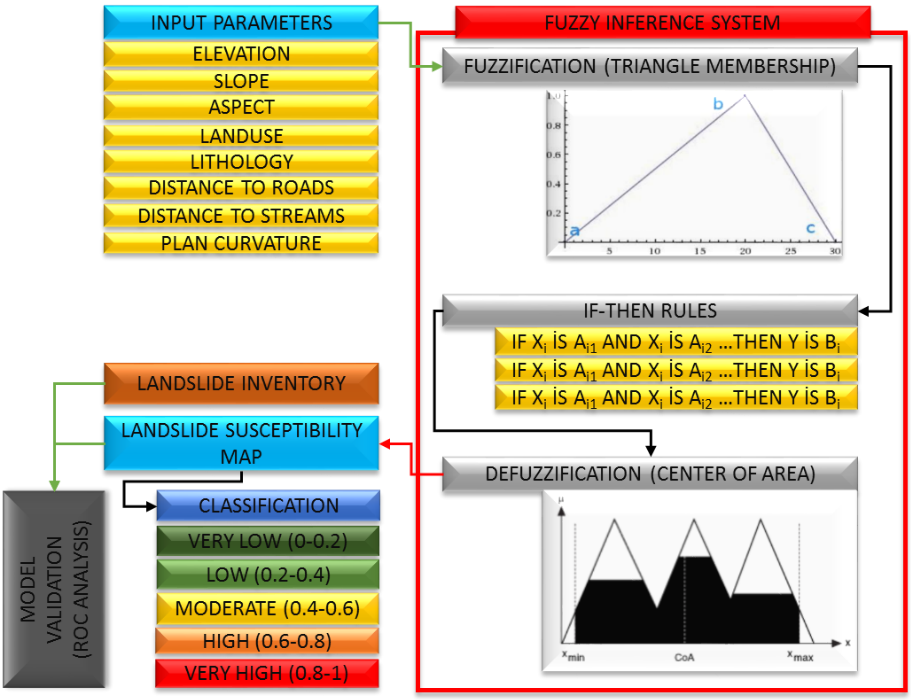


Figure 3. The workflow of fuzzy-rule based landslide susceptibility mapping
Şekil 3. Bulanık-kural tabanlı heyelan duyarlılık haritalama iş akış şeması

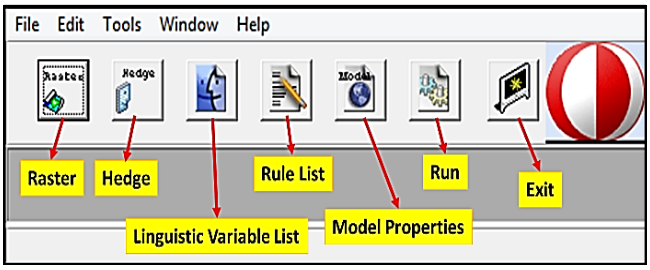
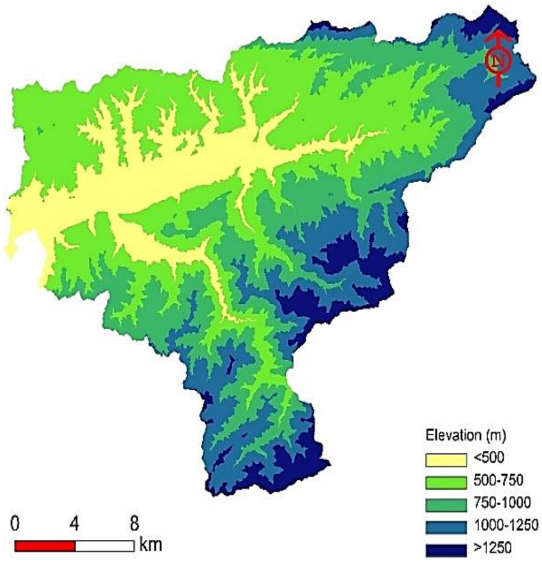
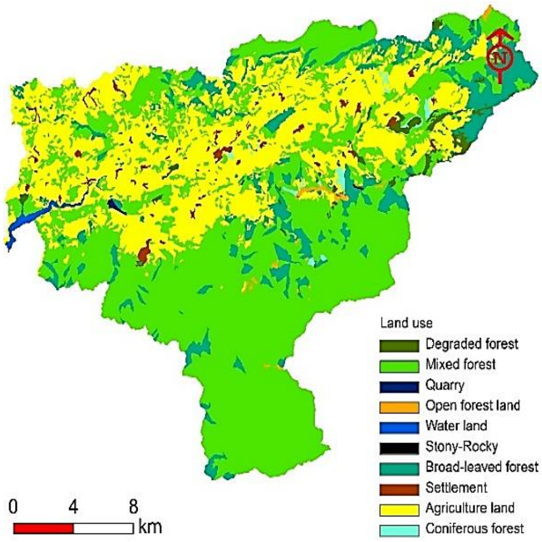


Figure 4. Graphical User Interface of FuzzyCell software (yellow rectangles show the name of buttons)
Şekil 4. FuzzyCell yazılımının kullanıcı grafik ara yüzü (sarı kutucuklar butonların isimlerini göstermektedir)

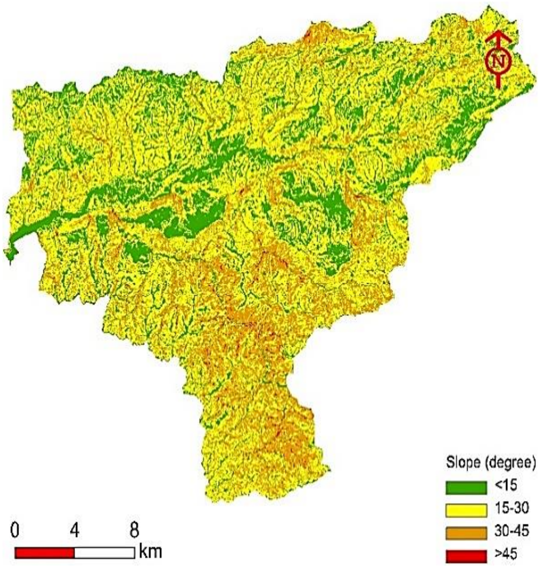
Based on Eker and Aydın (2014), for the comparison of two studies, same 8 landslide conditioning parameters were selected for generating landslide susceptibility mapping: land use, lithology, elevation, slope, aspect, distance to streams, distance to roads, and plan curvature (Figure / Şekil 5). The 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 were converted and stored in a raster format with 10 m grid resolution. ArcMap® software was used for the generation of all raster files as mentioned above. In the present study, Mamdani model was selected as fuzzy inference system. After input parameters in raster format entered to the software, firstly, fuzzification of obtained conditioning parameters was done. All parameters entered to the software should be in non-classified format. And except land-use and lithology, all raster files have continuous pixel values. In this process, all membership functions for each parameter were selected as Triangular membership function and class numbers of parameters defined in such a way that allow the simple model construction (Figure / Şekil 6). Then, fuzzy rules were created which appear in the form of IF-THEN (Table 1). “And” method was selected as “Algebraic Product”, while “Or” method was selected as “Algebraic Sum”. In total, 54 fuzzy rules were established after many attempts until finding out the best model refraining from complexity. Implication method and aggregation method of Mamdani model were selected as minimum and maximum, respectively. A fuzzy inference system can have both fuzzy sets and crisp values but the outputs are always fuzzy sets. Hence, defuzzification is made for converting fuzzy sets of outputs to crisp values. Center of Area (COA) was selected as defuzzification method in model. The output of FuzzyCell software is a raster file that its pixels show digit numbers of susceptibility values defined between 0-100 for the present study. Then the output of developed model was normalized between 0-1, and divided into five classes such as very low, low, moderate, high, and very high. Range values of susceptibility classes were selected as same with previously generated landslide susceptibility map for the comparison.



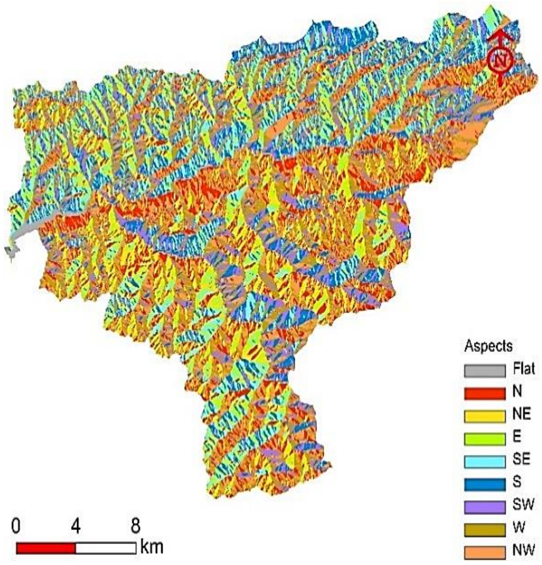
a. Elevation map
a. Yükselti haritası



b. Landuse map
b. Arazi kullanımı

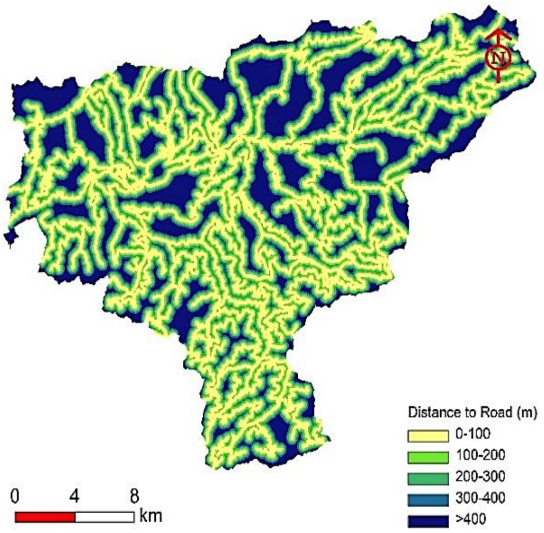


c. Slope map
c. Eğim haritası

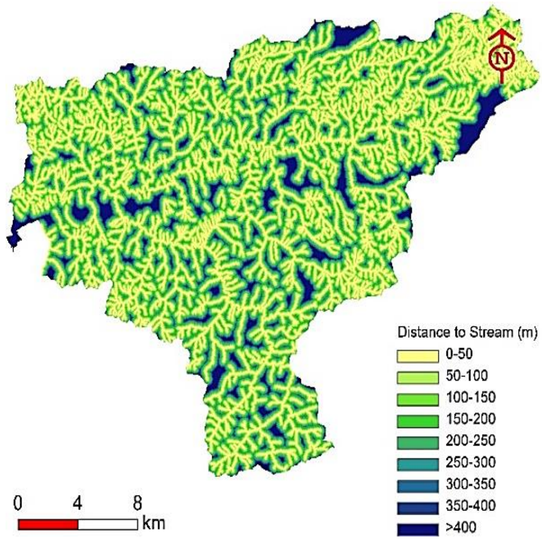


d. Aspect map
d. Bakı haritası

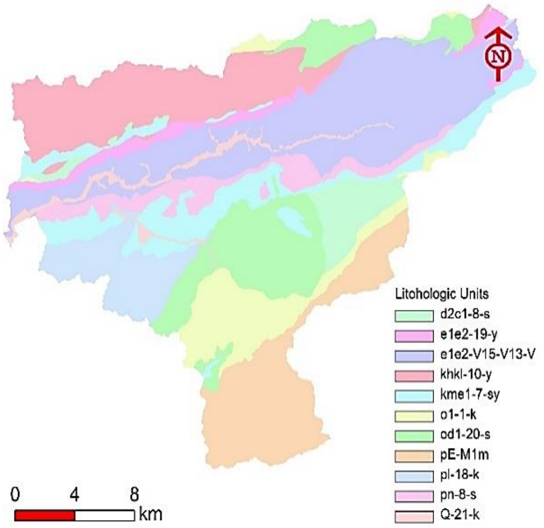
Figure 5. Maps of parameters used in the model (Eker and Aydın, 2014)
Şekil 5. Modelde kullanılan parametrelerin haritaları (Eker ve Aydın, 2014)



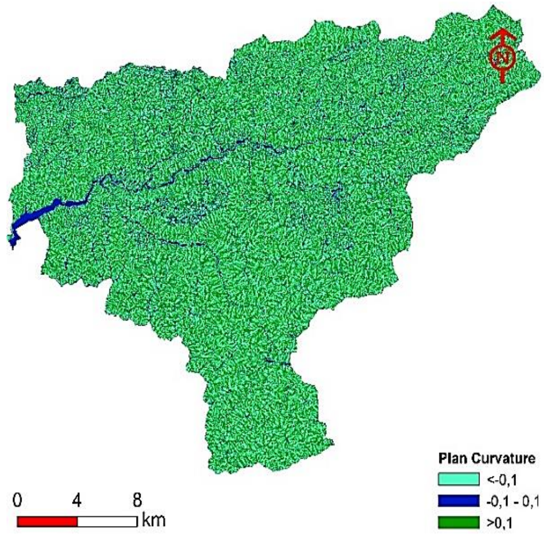
e. Distance to roads map
e. Yola uzaklık haritası



f. Distance to streams map
f. Dereye uzaklık haritası



g. Lithology map*
g. Litoloji haritası*



h. Profil curvature map
h. Profil eğrisellik haritası

Figure 5 (Cont.). Maps of parameters used in the model (Eker and Aydın, 2014)
Şekil 5 (Devam). Modelde kullanılan parametrelerin haritaları (Eker ve Aydın, 2014)

*(e1e2-V15-V13-V2-s is pyroclastic rocks-andesite-basaltic, od1-20-s is sandstone-mudstone-limestone, pE-M1m is metagranitoid, kme1-7-sy is argillaceous limestone, khkl-10-y is volcanic sedimentary rock, o1-1-k is sandstone, e1e2-19-y is sandstone-mudstone, d2c1-8-s is limestone, Q-21-k is quaternary-alluvium, pl-18-k is terrestrial clastics, pn-8-s is limestone (Paleocene faunal)

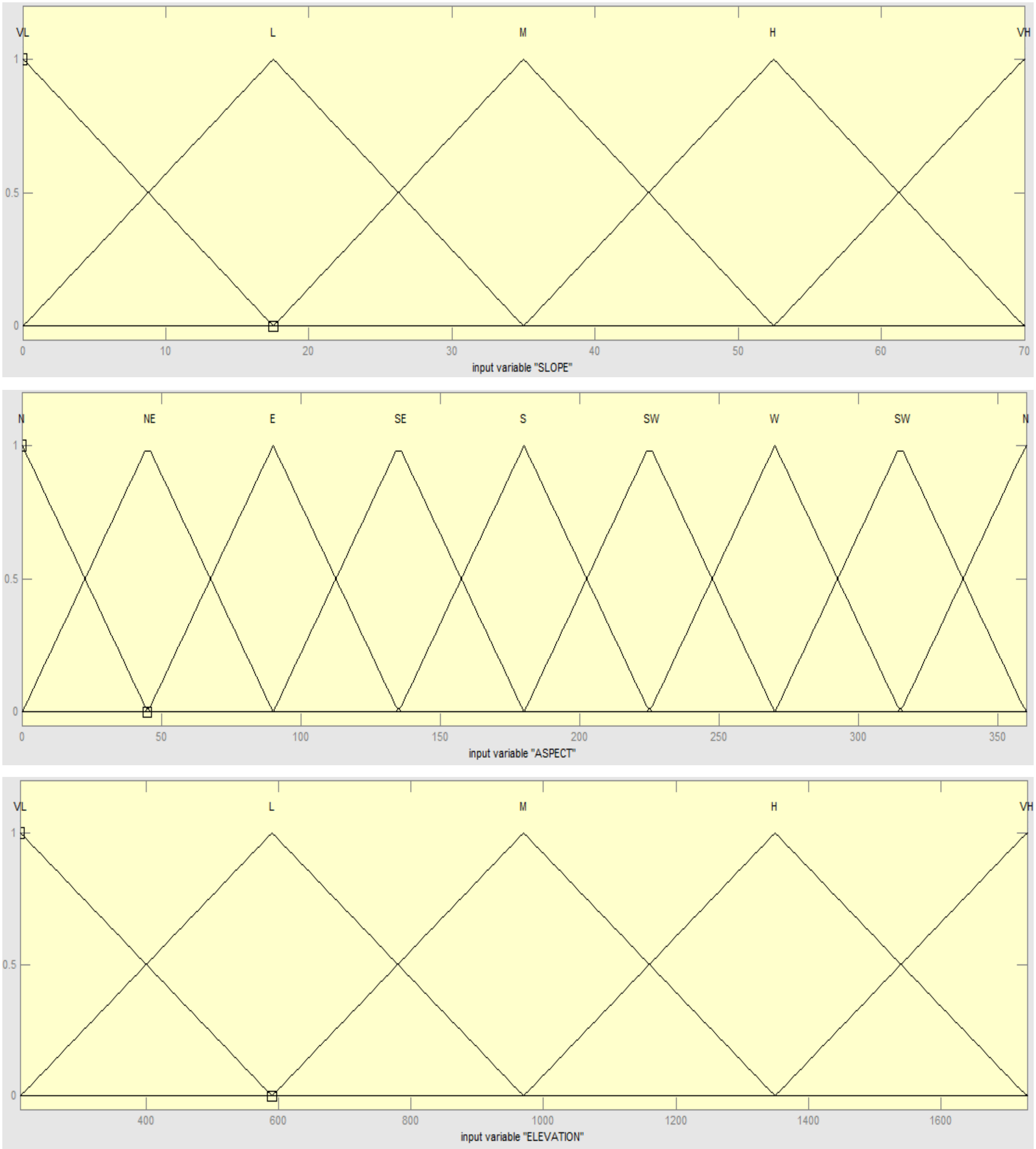


Figure 6. Some of fuzzified parameters used in model (top: slope, middle: aspect, bottom: elevation)
Şekil 6. Modelde kullanılan bulanıklaştırılmış bazı parametreler (üstte: eğim, ortada: bakı, altta: yükselti)

For the validation of generated landslide map in present study as well as comparison the results with previously generated landslide susceptibility map, the Area Under the Curve (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 the following equation as:

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

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. When AUC value is equal to 1, this means a perfect prediction, while if this value equal to or close to 0.5 means that the model couldn't be constructed (Pradhan, 2011; Begueria, 2006).

Table 1. Some of defined fuzzy rules (17 of 54 rules showed below)
Tablo 1. Tanımlanmış bazı bulanık kurallar (aşağıda 54 kuralın 17'si gösterilmektedir)

IF LndUse **is** Agr **AND** Lito **is** PRAB **AND** Slp **is** VL **AND** Elvt **is** VL **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** VH
IF LndUse **is** MxFr **AND** Lito **is** PRAB **AND** Slp **is** VL **AND** Elvt **is** VL **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** M
IF LndUse **is** St **AND** Lito **is** PRAB **AND** Slp **is** VL **AND** Elvt **is** VL **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** M
IF LndUse **is** BlFr **AND** Lito **is** PRAB **AND** Slp **is** VL **AND** Elvt **is** M **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** M
IF LndUse **is** DgFr **AND** Lito **is** PRAB **AND** Slp **is** H **AND** Elvt **is** M **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** H
IF LndUse **is** Wtr **THEN** Sscpt **is** VL
IF Lito **is** TrC **THEN** Sscpt **is** VL
IF LndUse **is** Agr **AND** Lito **is** ArL **AND** Slp **is** VL **AND** Elvt **is** VL **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** VH
IF LndUse **is** MxFr **AND** Lito **is** ArL **AND** Slp **is** M **AND** Elvt **is** VL **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** VH
IF LndUse **is** MxFr **AND** Lito **is** ArL **AND** Slp **is** VL **AND** Elvt **is** VL **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** H
IF LndUse **is** MxFr **AND** Lito **is** Mg **AND** Slp **is** VH **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** VH
IF LndUse **is** MxFr **AND** Lito **is** Mg **AND** Slp **is** H **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** H
IF LndUse **is** MxFr **AND** Lito **is** SnS **AND** Slp **is** VH **AND** DtoR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** VH
IF LndUse **is** Agr **AND** Lito **is** VSR **AND** DtR **is** VC **AND** DtoS **is** VC **THEN** Sscpt **is** VH
IF Aspct **is** N **THEN** Sscpt **is** H
IF Aspct **is** **NOT** N **THEN** Sscpt **is** M
IF LndUse **is** Agr **AND** Slp **is** L **OR** LndUse **is** Agr **AND** Slp **is** VL **THEN** Sscpt **is** M

Abbreviations:

LndUse = Landuse	VH = Very High	DgFr = Degraded Forest
Aspct = Aspect	H = High	Wtr = Water
Lito = Lithology	M = Medium	TrC = Terrestrial Clastics
Slp = Slope	VL = Very Low	PRAB = Pyroclastic Rocks-Andesite-Basaltic
Elvt = Elevation	L = Low	ArL = Argillaceous Limestone
DtoR = Distance to Road	VC = Very Close	VSR = Volcanic Sedimentary Rock
DtoS = Distance to Stream	Agr = Agriculture	Mg = Metagranitoid
Sscpt = Susceptibility	MxFr = Mixed Forest	SnS = Sandstone-Mudstone-Limestone
	St = Settlement	BlFr = Broad-leaved Forest

3. RESULTS AND DISCUSSION

A landslide database of Yığılca Forest District located in West Black Sea Region of Turkey is updated following previous study made by the authors in the area. A total of 315 landslides of which 27 landslides are newly added, are found in the database. The area is located very close to North Anatolian Fault Zone and also the region is mountainous with steep slopes. But unfortunately, there is no information about what triggering factor is dominant. Landslide records in Turkey don't include temporal information of events. As a consequence of this situation, risk/hazard mapping of landslide is actually impossible. Hence fuzzy rule-based landslide susceptibility map was generated.

All model construction was made by using FuzzyCell software in the present study. The output of developed fuzzy inference system, i.e. fuzzy rule-based landslide susceptibility map, is shown in Figure / Şekil 7. In addition, in Figure 8, landslide susceptibility map previously generated using logistic regression model by the authors is shown. When the two susceptibility maps were compared, fuzzy rule-based landslide map shows less susceptibilities than previously generated susceptibility map. Because susceptibility varies between 32 and 67 (in range 1-100). According to classified normalized landslide susceptibility map, in Yığılca Forest District, 32.89% of the total area has high and very high susceptibility while 29.59% of the area has low and very low susceptibility. The remaining area of 37.52% is located in moderate susceptibility. The areal distribution of susceptibility classes in study area were given in Table / Tablo 2.

For the validation of developed map, AUC value was used and calculated as 0.703. When compared to previous study made in the same district by Eker and Aydın (2014), AUC value used for validation is slightly less (AUC = 0.905). In addition, the AUC value of developed fuzzy model is less than the results of some similar studies. For example, according to Pradhan (2011) who used fuzzy relation based cross application for landslide susceptibility mapping, the AUC values were obtained higher 0.85 in average. Besides, some studies used fuzzy relations showed that AUC value of application with some fuzzy operators such as OR and AND, can be around 0.7 (Lee, 2007; Ercanoğlu and Temiz, 2011). Akgün et al. (2012) who made most similar study to the present study in terms of methodology, also determined landslide susceptibility with AUC value 0.855. They constructed FIS model with total 192 if-then rules. And also, except lithology parameter, all of parameters were formed by two membership functions, while lithology had three membership functions (they used 7 conditioning parameters in total). In the present study, 8 conditioning parameters were used and except lithology and landuse, all of parameters includes 5 membership functions (very low, low, moderate, high, and very high) while lithology parameter has 11 membership functions and landuse parameter has 10 membership functions. And in total 54 if-then rules were used to construct model. These differences in the results of models are originated the following reasons: fuzzy rule based model completely (1) depends on how parameters are classified and fuzzified and also (2) depends on how truly the expert composed the rules. Even though many attempts of fuzzy rule definitions, in order to increase validity of model different compositions of fuzzy rules should be tested.

Table 2. Distribution of susceptibility classes and comparison with LR method
Tablo 2. Duyarlılık sınıflarının dağılımı ve LR yöntemi ile karşılaştırılması

Susceptibility Class	**The Percentage of Area (Fuzzy Rule Based)**	**The Percentage of Area (Logistic Regression)**	**Difference of two models**
Very low (0-0.2)	11.23	16,9	-5.67
Low (0.2-0.4)	18.36	40,5	-22.14
Moderate (0.4-0.6)	37.52	28,5	9.02
High (0.6-0.8)	30.23	13,4	16.83
Very high (0.8-1)	2.66	0,7	1.96

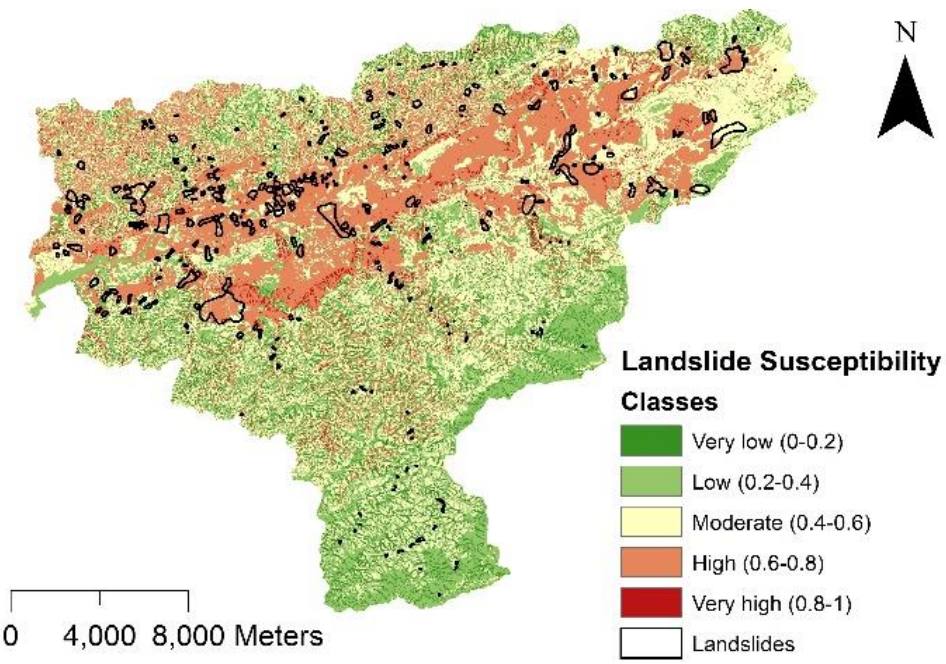


Figure 7. Fuzzy-rule based landslide susceptibility map
Şekil 7. Bulanık-kural tabanlı heyelan duyarlılık haritası

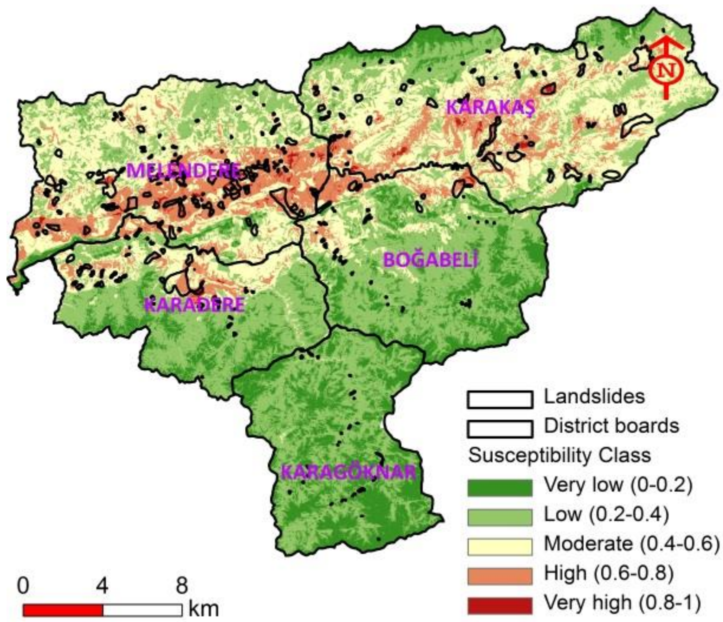


Figure 8. Landslide susceptibility map generated by logistic regression model (Eker and Aydın, 2014)
Şekil 8. Lojistik regresyon modeli ile üretilen heyelan duyarlılık haritası (Eker ve Aydın, 2014)

4. CONCLUSIONS

The Yığılca Forest District located in the landslide prone Western Black Sea Region of Turkey suffers from landslides. Landslides especially cause important damages over the roads as well as settlement and agricultural lands where hazelnut gardens are common. A landslide inventory was made by means of fieldwork following the study previously made by the authors in the area in order for updating landslide records. Landslide susceptibility map was formed by using fuzzy inference system, called Mamdani model. In the study, generated susceptibility map was compared with previously generated landslide susceptibility map by using logistic regression model by the authors. In the present study, it is aimed to construct very simple model. That's why number of if-then rules were defined as less as possible without making any reduction in the number of class of parameter. Even though, a great number of landslide susceptibility mapping papers have been published in landslide literature we believe that the methodology of the present study will provide a support to improve the landslide susceptibility maps.

For the model construction, FuzzyCell software was used. FuzzyCell software enables to use fuzzy rule based model in raster data. This software has many advantages such that it works as integrated with ArcMap® software. The only disadvantage of the software is that it has interface which causes loss of time in the stage of definition of if-then rules. But even so, this software provides a solution for application fuzzy rule based models in landslide susceptibility mapping studies.

Fuzzy models are useful since its capacity of incorporating with expert knowledge. However, it is a disadvantage that there is not a standard method available for transforming expert's knowledge to fuzzy membership function and also for creating fuzzy rules. Also, there are many ways of interpreting fuzzy rules, combining the outputs of several fuzzy rules and defuzzifying the output. Even so, as it is showed in many studies made for mapping landslide susceptibility, GIS-based fuzzy applications provide very valuable facilities for reasoning, which makes it possible to take into account inaccuracies and uncertainties.

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