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ORIGINAL ARTICLE

GIS-based landslide susceptibility for Arsin-Yomra (Trabzon, North Turkey) region

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Abstract The purpose of this study is to assess the susceptibility of landslides around Yomra and Arsin towns near Trabzon, in northeast of Turkey, using a geographical information system (GIS). Landslide inventory of the area was made by detailed field surveys and the analyses of the topographical map. The landslide triggering factors are considered to be slope angle, slope aspect, distance from drainage, distance from roads and the weathered lithological units, which were called as ''geotechnical units'' in the study. Idrisi and ArcGIS packages manipulated all the collected data. Logistic regression (LR) and weighted linear combination (WLC) statistical methods were used to create a landslide susceptibility map for the study area. The results were assessed within the scope of two different points: (a) effectiveness of the methods used and (b) effectiveness of the environmental casual parameters influencing the landslides. The results showed that the WLC model is more suitable than the LR model. Regarding the casual parameters, geotechnical units and slopes were found to be the most important variables for estimating the landslide susceptibility in the study area.

Keywords Landslide · Logistic regression · GIS · Weighted linear combination · Turkey

Introduction

Landslides are much more common natural hazards in the world than any other hazards such as earthquakes, volcanoes and floods. They may cause loss of life and property, damage natural resources and hamper infrastructure projects such as roads, bridges and communication lines (Saha et al. 2002).

Landslide is the second most common natural hazard in Turkey (Ildir 1995) and landslides especially affect the Black Sea region of Turkey. This region is characterized by steep topography, and is subjected to heavy precipitation. Due to these adverse effects, the region is prone to extensive and severe landslides (Ercanoğlu and Gökçeoğlu 2002).

The study area is located in the eastern part of the Black Sea Region, between the towns of Arsin and Yomra within Trabzon province, Turkey. The area is 38.87 km^2 and located 15 km to the south of the city center of Trabzon (Fig. 1) which is one of the most important harbour cities in Turkey.

The study area has both natural and artificial triggers for landsliding. While heavy precipitation, stream erosion of slope toes, weathering of the bedrock are the natural triggers, steeply and improperly cut slopes, poorly controlled surface drainage and uncontrolled settlement and agricultural activities are the artificial triggers.

It has been planned to construct an expressway route in the study area. This route is expected to be an alternative solution to the traffic problem of the city. Although there are no major civil engineering studies in this area, there are many geological problems to be investigated. Since landsliding is probably the most important geological problem in the area, a

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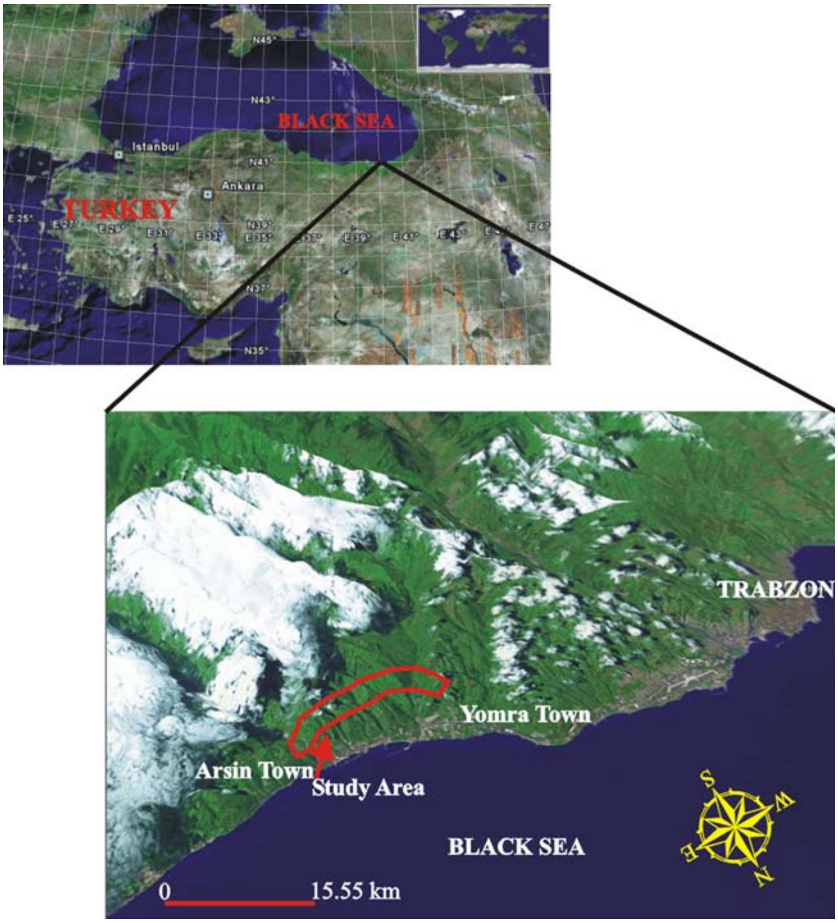


Fig. 1 Location of the study area from Landsat 7 ETM+ satellite image

landslide susceptibility mapping of the area was carried out.

Geographical information system (GIS) is a tool, which has been used in many studies to carry out landslide susceptibility assessment (Lee 2005). Recently, there have been many studies carried out to determine the landslide susceptibility assessment using GIS and in many of these studies, quantitative and qualitative models have been used (Lee and Min 2001; Lee et al. 2002a; Ayalew et al. 2005; Ohlmacher and Davis 2003; Süzen and Doyuran 2004a, b; Ayalew and Yamagishi 2005; Gökçeoğlu et al. 2005; Lee et al. 2002b; Lee et al. 2004; Barredo et al. 2000).

In general, there are two approaches used for landslide susceptibility assessment in literature (Ohlmacher and Davis 2003). The first is a deterministic approach based on mathematical models of the physical mechanism controlling the slope failure (Kramer 1996). In order to use deterministic models, there is a need to determine the material properties such as mechanical characteristics, degree of water saturation, shear strength parameters and etc. Unfortunately, obtaining such data over large areas is quite difficult (Terlien et al. 1995). The second approach makes use of the statistical and probabilistic methods. In this approach, it is assumed that occurrences of previous landslides can be related arbitrarily to measurable features of landscape (Ohlmacher and Davis 2003) and these features can be utilized to guess the future landslide occurrences. For this reason, statistical approaches, logistic regression and weighted linear combination were preferred to construct the landslide susceptibility map of the study area.

Dai and Lee (2002), Süzen (2002), Ohlmacher and Davis (2003), Süzen and Doyuran (2004b) and Lee (2005) successfully applied the logistic regression method to landslide susceptibility mapping. The primary assumption in logistic regression approach is to compare the possibility of landslide occurrences with the actual landslide frequency. Ayalew et al. (2004, 2005) have used the weighted linear combination model, which is a hybrid method between qualitative and quantitative methods in the landslide susceptibility assessments. In the weighted linear combination model, the class weights of the landslide triggering factors are determined using the analytical hierarchy process (AHP) and then each factor is multiplied with the determined weight values and so the weighted factor maps are obtained for the studied area. Finally, all the weighted factor maps are overlaid and a landslide susceptibility map is produced.

For the study area, the landslide occurrences were mapped by the detailed field surveys and assessment of the topographical map and then, a landslide inventory map was constructed using GIS. Topography, geotechnical units, drainage and road networks database were created in vector format and then, the obtained casual factor maps were converted into 20 × 20 m grid. Then, using a logistic regression model, the relation between the landslide location and the triggered factors were analysed and a formula for the landslide occurrence possibility was obtained by Idrisi software. This formula was used to calculate the landslide susceptibility index map, which was reclassified so as to represent the landslide susceptibility in the area. In weighted linear combination model, the class weights of the landslide triggering factors were determined using the analytical hierarchy process (AHP). Then each factor was multiplied with the determined weight values and the weighted factor maps were obtained. In the final step, all the weighted factor maps were overlaid and a landslide susceptibility map was constructed. In order to determine the validation of the two landslide susceptibility maps, both were compared with the landslide inventory map of the study area. Additionally, the two maps were also compared with each other to establish the similarities between them.

In the study, GIS Software, Idrisi Kilimanjaro and ArcGIS 8.2 version software packages were utilized as the basic analysis tools for spatial analysis and data manipulation.

Local geology

The lithological units in the study area are upper Cretaceous-Paleocene rhyolite-rhyodacite and pyroclastics, named Çayırbağ Formation, sandstone, marl, clayey limestone and tuff alternation, named Bakırköy Formation, Eocene andesite- basalt and pyroclasts, named Kabaköy Formation, Pliocene aged conglomerate and breccia, named Besirli Formation and the Quaternary deposits as terraced fluvial deposits and alluvium (Fig. 2). Some brief descriptions of these lithological units are summarized below.

Çayırbağ formation

They are the oldest lithological units that outcrop within the study area. They form basement rocks consisting of greenish grey, pinkish and purplish grey rhyolite-rhyodacite and pyroclastics with rhyodacite, trachite. The particle size of the tephra pyroclasts varies from 1 to 10 cm. The rock mass is characterized by prismatic columnar and volcanogenic dome structures. The columnar discontinuity surfaces show hydrothermal alteration products such as hematite and limonite (Güven et al. 1993; Akgün 2001).

Bakırköy formation

The Bakırköy formation is observed within the Arsin Niyazioğlu and Cumhuriyet districts and the Harmanlı village area. The formation is generally composed of grey marl, grey-white clayey micritic limestone, sandy limestone, acidic tuff and partly sandstone. Due to the presence of faults, mylonite and hydrothermal alteration products such as hematite and limonite can be observed in some parts of the study area (Güven et al. 1993).

Kabaköy formation

The Kabaköy formation is observed in the western, northern and eastern parts of the investigation site. It is composed of greenish-grey basalt and has loose augite and grey, greenish-grey andesite. These volcanic units are found with sandstone, sandy limestone and marl

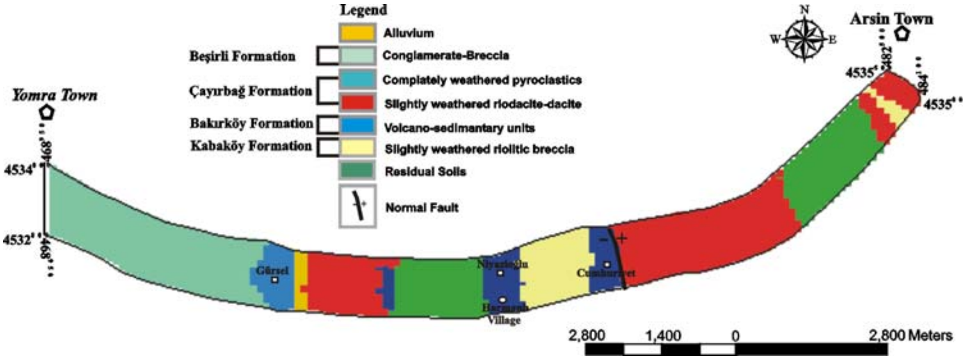


Fig. 2 Lithological map of the study area

beds. Field descriptions of the volcanic rocks are difficult because they are extensively hydrothermally altered, with alteration products such as limonite and hematite commonly present.

Besirli formation

The Besirli formation is observed throughout the western part of the study area. The formation comprises weakly cemented conglomerates and breccias. Also, coarse sandstone and thickly bedded sandy limestone and basaltic agglomerates can be observed within this formation.

Unconsolidated recent sediments (alluvium and terrace deposits)

Holocene recent sedimentary units are represented by alluvium of the streams, river valleys and marine terrace deposits. In the investigation area, the marine terraces extend along the coast as a narrow strip of wave-cut surfaces. The widest outcrop can be observed in Yomra town centre. It is composed of block, gravel, sand, silt and clay sized materials. The thickness of the terrace deposits varies in the range of 0.5–10 m. The recent alluvium is observed along major and minor streams comprising sand, silt, gravel and block sized materials. Alluvium is common along Yomra and Arsin stream valleys and varies in thickness from 15 to 20 m (Güven et al. 1993).

Data

There were five factors taken into consideration in determining the landslide susceptibility of the study area. These factors were slope angles, slope aspects, distance from drainage path, distance from road cut and geotechnical units. Initially, a digital elevation model (DEM) of the study area was created using the topographical map. Contours on the 1:25,000 scale topographical map were used to produce a DEM of the area. The selection of appropriate pixel size for the positional accuracy and precision of susceptibility levels in the resultant map was a critical point. According to USGS (1993), the positional accuracy needed for 1:25,000 scale maps must be ±12.5 m. For this reason, a pixel size of 20 m was selected for the constructed DEM. The slope angles and slope aspects were calculated using the DEM of the area. Drainage and road networks were derived from the 1:25,000 scale topographical map and the aerial orthogonal distance of all pixels to drainage and road lines were calculated. The first author in the field prepared a 1:10,000 scale geotechnical unit map and then it was digitized. In this map, the lithological units were assessed in terms of not only their lithological properties such as petrographical characteristics but also their weathering grades (Akgün 2001). Weathering grade classification for this study was applied using procedure proposed by ISRM (1981).

Susceptibility maps

Logistic regression model

Logistic regression allows forming a multivariate regression relation between a dependent variable and several independent variables (Atkinson and Massari 1998; Hosmer and Lomeshow 2000; Süzen 2002; Süzen and Doyuran 2004b). Logistic regression is useful to predict the presence or absence of a characteristic or outcome based on values of a set of predictor variables (Lee 2005). In the case of landslide susceptibility mapping, the purpose of logistic regression would be to find the best fitting model to describe the relationship between the presence or absence of landslide which is called as dependent variable and a set of independent parameters such as slope angle, lithology, distance to drainage and etc. (Ayalew and Yamagishi 2005). In logistic regression, dependent variable is coded as "1" and "0" to indicate the presence and absence of a landslide respectively. Coefficients determined in the logistic regression can be used to estimate ratios for each of the independent variables. The logistic model representing the maximum likelihood regression model can be expressed in its simplest form as:

$$P = \frac{1}{1 + \mathrm{e}^{-z}} \tag{1}$$

where p is the probability of an event occuring. P is the estimated probability occurence in the current situation. Since z value varies from $-\infty$ to $+\infty$, the probability varies from 0 to 1 on an S-shaped curve and Z is defined as:

$$Z = Bo + B_1X_1 + B_2X_2 + \cdots + B_nX_n, \tag{2}$$

where Bo is the intercept of the model, n is the number of independent variables. The B_i (i = 0, 1, 2,..., n) are the slope coefficients of the logistic regression model and the X_i (i = 0, 1, 2,..., n) are the independent variables.

Based on Eqs. 1 and 2, the equation of logistic regression can be written in the following extended form

$$\mathrm{Logit}(P) = \frac{1}{1 + \mathrm{e}^{-Bo + B1X1 + B2X2 + \cdots + BnXn}}. \qquad (3)$$

Weighted linear combination model

Weighted linear combination (WLC) is likely to be the best known and commonly used multicriteria-GIS method (Eastman 1999; Jiang and Eastman 2000; Şener et al. 2006). WLC is a method in which triggered factors effecting a landslide can be combined by applying primary and secondary level weights. In this method, a primary issue is to assign weights to each factor separately. There are many techniques such as the statistical index method (Wi) (Van Westen 1997), weighting factor (WF) (Çevik and Topal 2003; Öztekin and Topal 2005) and analytical hierarchy process (AHP) (Saaty 1980; Saaty and Vargas 2001; Ayalew et al. 2004, 2005; Şener et al. 2006) to find weights. In this regard, the analytical hierarchy process (AHP), a theory for dealing with complex technological, economical and socio-political problems, is an appropriate method for deriving the weight assigned to each factor (Saaty 1980).

Basically, AHP is a multi-objective, multi-criteria decision-making approach that employs a pair-wise comparison procedure to arrive at a scale of preference among a set of alternatives (Malczewski 1999). Specifically, the weights are determined by normalizing the eigenvector associated with the maximum eigenvalue of the (reciprocal) ratio matrix. In this method, the pair-wise matrix is used and ranking of all factors is made by a continuous scale ranging from 1/9 to 9 (Table 1). When the factor on the vertical axis is more important than the factor on the horizontal axis, this value varies between 1 and 9. Contrary to this, the value varies between the reciprocals 1/2 and 1/9. Weight values are calculated by taking the main eigenvector of the matrix (Malczewski 1999). In AHP, the consistency utilized to construct a matrix is checked by a consistency ratio (CR). CR is used to show the probability that the matrix judgements were randomly generated (Saaty 1980)

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \qquad (4)$$

where RI is the average of resulting consistency index depending on the order of the matrix given by Saaty (1980) and CI is the consistency index and can be expressed as:

$$\mathrm{CI} = \frac{(\lambda_{\max} - n)}{(n - 1)}, \qquad (5)$$

where $\lambda_{\max}$ is the largest or principal eigenvalue of the matrix and can be easily calculated from the matrix, n is the order of the matrix.

In order to be acceptable of the computed weights, the consistency ratio must be less than 0.1 (Malczewski 1999; Saaty 2000). A consistency ratio above 0.1 requires revisions of the judgements in the matrix because of an inconsistent treatment of particular factor ratings.

Application of the methods

Logistic regression applications

The spatial relationship between landslide occurrence and the landslide triggered parameters was evaluated using the logistic regression method. The statistical results of the model are summarized in Table 2. The statistical assessment was carried out using IDRISI. In this assessment, a logistic regression equation was obtained as shown in Eq. 6.

$$\begin{aligned} Y = {} & -3,2832 + (0.004559 \times \text{slope}) \\ & + (0.158070 \times \text{geotechnical unit}) \\ & - (0.003424 \times \text{road}) - (0.000244 \times \text{drainage}) \\ & - (0.000769 \times \text{aspect}), \qquad (6) \end{aligned}$$

Table 1 Scale of preference between the parameters in AHP (Saaty 2000)

Scales	Degree of preferences
1	Equally
3	Moderately
5	Strongly
7	Very strongly
9	Extremely
2, 4, 6, 8	Intermediate
Reciprocals	Opposites

Table 2 Summary statistics of the logistic regression function

Statistic	Value
Number of sampled observations	2,000,000
2 ln L	103,325
2 ln $L0$	142,249
Pseudo R^2	0.2736
Goodness of fit	432,315.31
ROC	0.93

L Likelihood

where slope is slope angle value, geotechnical unit is lithological units distinguished by its weathering grades and lithological properties, road is distance from road value, drainage is distance from drainage path value and aspect is aspect angle value.

According to Menard (1995), the Pseudo R^2 value, which can be calculated from $1-\left(\frac{\ln L}{\ln L_0}\right)$, considerably points out how the logit model fits the dataset. So, Pseudo R^2 equal to 1 indicates a perfect fit, whereas 0 shows no relationship (Ayalew and Yamagishi 2005). When a pseudo R^2 is greater than 0.2, this is an evidence of a relatively goodness of fit (Clark and Hosking 1986). Another indicator of the goodness of fit is ‘‘Relative Operating Characteristic’’ (ROC) value which compares a Boolean map of reality (occurrence of landslide) with the probability map. If the ROC value is 1, it indicates a perfect fit whereas ROC equal to 0.5 shows the random fit.

In this study, Pseudo R^2 and ROC values are found to be 0.2736 and 0.93 respectively as shown in Table 2. Thus, these values indicate that the logistic regression method for this study gives acceptable values.

According to the Eq. 6, the slope angle and geotechnical unit's coefficients are positive, the road distance, drainage distance and aspect coefficients are negative. This means that the slope and geotechnical units are positively related to the occurence of landslide whereas the aspect, drainage and road distances indicate a negative relation with the landslide occurrence in the study area. Especially, the ‘‘geotechnical units’’ parameter has a higher effect on the occurrence of landslides than the other landslide triggering parameters. Due to the fact that the weathering grades of the lithological units in the study area differ from slightly weathered to completely weathered, this makes the rocks more susceptible to landslide occurrence. The slope also plays an important role with the geotechnical units in the development of landslides. Since the coefficients of the aspect and drainage distance are very close to 0, they have a little impact on the development of landslides. The road distance has a more impact than the drainage distance and aspect parameters, due to the uncontrolled slope cuts for the purpose of settlements, affecting the toe stability of the slopes.

Based on the statistics and coefficients of the logistic regression model, a predicted map of probability defined by numbers that are constrained to fall between 0 and 1 was produced. In this map, numbers, which are close to 1, indicate the better likelihood whereas the numbers close to 0 show poor probability. In Fig. 3, the landslide occurrence probability map produced in this study is shown. After obtaining the probability map, a necessity arose to divide this map into susceptibility classes. Generally, the proposed methods for this purpose depend on the optimum bin width classification of the histograms of various parameters. In literature, there are many methods to realise this necessity (Süzen and Doyuran 2004a, b; Ayalew and Yamagishi 2005; Guzetti et al. 1999; Lee and Min 2001; Ohlmacher and Davis 2003; Ayalew et al. 2004). Ayalew and Yamagishi (2005) have used four classification systems that use quantiles, natural breaks, equal intervals and standart deviation. They have found that quantile based classification system has a disadvantage in that it places widely different values into the same class. Natural breaks are better when the big jumps in data values exist. Equal intervals were also determined as not helpful since they emphasize one class relative to others. Finally, they have chosen the standard deviation method because it uses the mean to generate class breaks.

In this study, the standard deviation method was used as well and the probability map was divided into five susceptibility classes: very low, low, medium, high and very high. According to this susceptibility map, 21.62% of the total area is found to be very low susceptible. Low, medium and high susceptible zones constitute 50.55, 19.40 and 7.82% of the area respectively. The very high susceptible area is 0.55% of the total study area (Fig. 4).

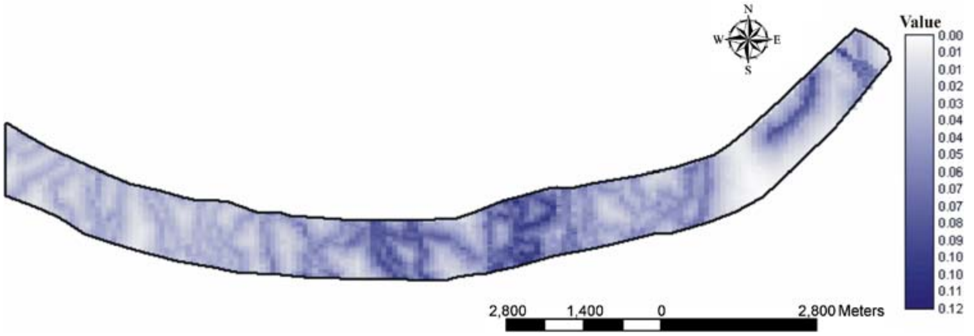


Fig. 3 Probability map produced by the logistic regression model

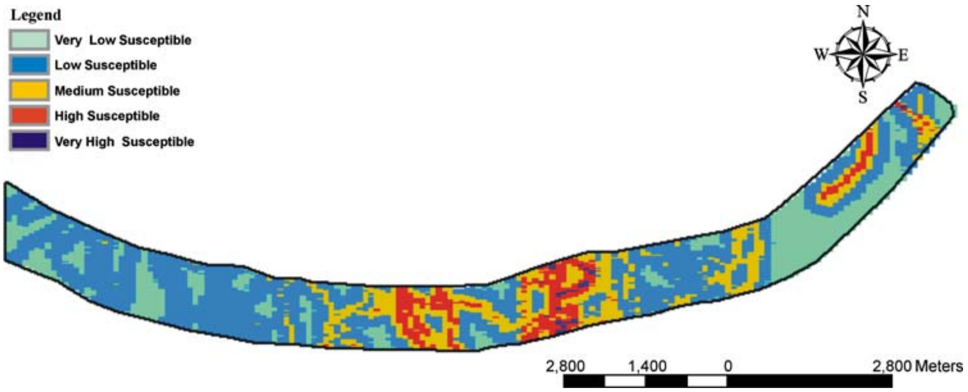


Fig. 4 Landslide susceptibility map produced using the logistic regression model

Weighted linear combination applications

In order to produce a landslide susceptibility map using WLC model, firstly, the primary level weights which are rule based in the ratings giving to each class of a parameter on the basis of a certain criterion were determined. To find factor weights, AHP (analytic hierarchy process) approach was utilized. For this purpose, a pair-wise comparison matrix with score given in Table 3 was constructed. The appropriate scores used in this study were chosen according to dominant site characteristics. Using five parameters, which are the same as those used in the logistic regression assessment, the comparison matrix was constructed. The diagonal boxes of a pair-wise comparison matrix always take a value of 1. The boxes in the upper and lower halves are symmetrical with one another and the corresponding values are reciprocal with each other. When the matrix is made, the weights will be gained using the factor layers as input. Then, the weights are taken into account as the average of all possible ways of comparing the casual factors (Malczewski 1999; Ayalew and Yamagishi 2005).

In this study, the weight value of the geotechnical units is higher than those of slope angle, road distance, aspect and drainage distance (Table 3).

The consistency ratio is found to be 0.01 and this value expresses the proper degree of consistency ratio utilized to produce the comparison matrix because it is less than 0.1.

In order to produce a landslide susceptibility map by WLC model, the weights corresponding to parameters were multiplied by the relevant parameter maps and then, all the weighted parameter maps were overlaid. In this way, a map having a continuous scale of numerical values was obtained. At this point, a necessity of dividing these values into susceptibility classes has appeared. For this purpose, the standard deviation method was used for the susceptibility map constructed by logistic regression model. Based on this method, five susceptibility classes were distinguished such as very low, low, medium, high and very high (Fig. 5). According to this susceptibility map, 8.94% of the study area is very low susceptible and the low, medium and high susceptible zones form 22.45, 23.91 and 24.59% of the study area respectively. It is estimated that 20.08% of the total area is very high susceptible.

Validation of the results

In literature, there are different validation methods. Lee (2005) used the area under curvature method. In this method, he compared the known landslide location data with the produced landslide susceptibility maps and made rate curves so that he can assess the prediction accuracy using the area under curve. Süzen and Doyuran (2004a) developed the "seed cell area index (SCAI)" method to compare the two landslide susceptibility maps which were constructed by bivariate

Table 3 The pair-wise comparison matrix, parameter weights and consistency ratio

Parameters	Aspect	Road distance	Geotechnical units	Drainage distance	Slope	Weights
Aspect	1	1/2	1/5	2	1/4	0.0854
Road distance	2	1	1/2	3	1/2	0.1681
Geotechnical units	5	2	1	7	2	0.4179
Drainage distance	1/2	1/3	1/7	1	1/4	0.0557
Slope	4	2	1/2	4	1	0.2729

Consistency ratio: 0.01 < 0.1 (acceptable)

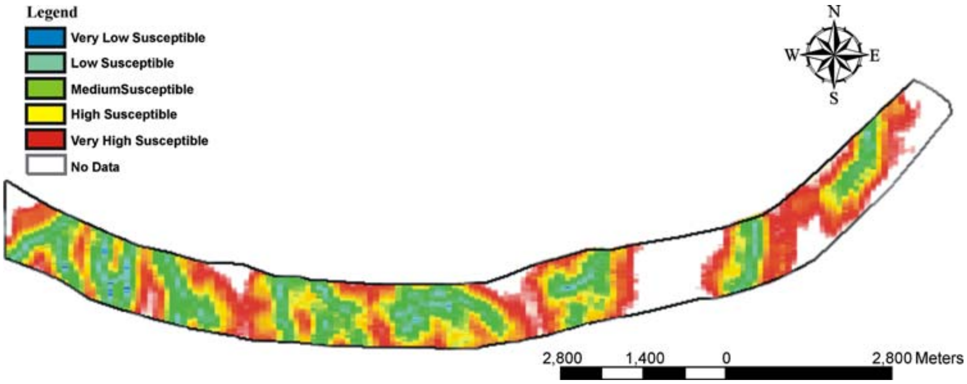


Fig. 5 Landslide susceptibility map produced using the weighted linear combination model

and logistic regression methods. In this method, the area percent values are divided with the landslide seed cell percent values to find density of landslides among the classes. Ayalew et al. (2005) used simple overlay method. In this method, two susceptibility maps were separately overlaid with the active landslide zones map and the landslide occurrence percentage in all susceptibility classes for both maps were determined. In this study, the basic overlay method was applied as well. With this operation, landslide occurrence percentages falling to all the susceptibility classes of the two susceptibility maps were determined (Figs. 6, 7).

In order to verify the obtained results, the two susceptibility maps and the landslide inventory map were compared. About 13 landslide zones form 4.2% of the study area (Fig. 8). The eastern part of the study area has more prone to landslide than the western part.

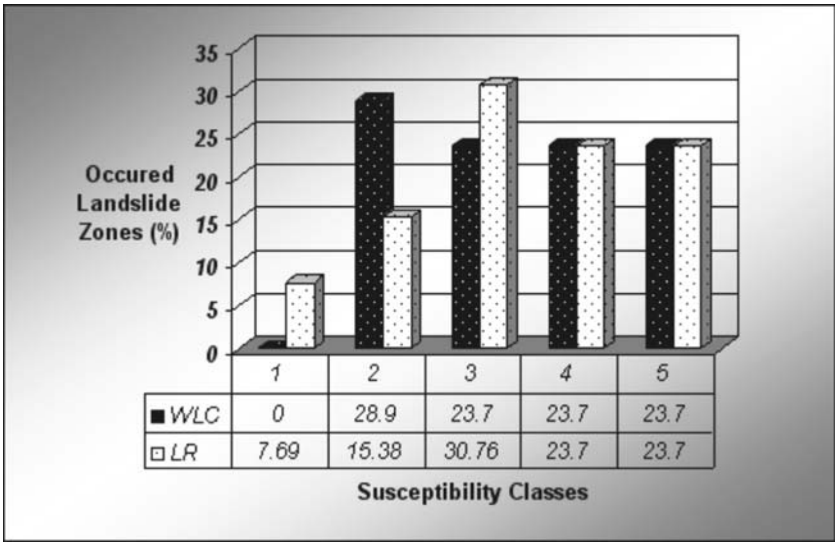
Looking at Fig. 6, it is easy to see that many of the occurred landslides (54.46% in total) fall into the medium susceptibility class (3) of both susceptibility maps. In both maps, high (4) and very high (5) susceptibility classes have the same amount of landslide occurrence. Whereas the very low (1) susceptibility class in WLC map has no landslide occurrence, in the LR map, 7.69% of the landslides fall into this class.

In Fig. 7, the susceptibility classes obtained by the two models were graphed. Looking at this figure, it is clear that the medium, high and very high susceptibility classes in LR model form the small parts of all the study area. However, this is not valid for the WLC model. Whereas the distribution of the different grade susceptibility areas in the WLC model is close to a normal distribution, they have a skewness in the LR model.

It is easy to conclude with results that the field recorded landslide zones have more fit with the WLC map than LR map. This indicates that the landslide susceptibility prediction is better by WLC than the LR method.

Discussion and conclusions

The production of landslide susceptibility map is a primary issue in hazard assessment. In the last two



	1	2	3	4	5
■ WLC	0	28.9	23.7	23.7	23.7
☐ LR	7.69	15.38	30.76	23.7	23.7

Fig. 6 A histogram showing the percentages of the observed landslide zones falling into the susceptibility classes of the WLC and LR susceptibility maps

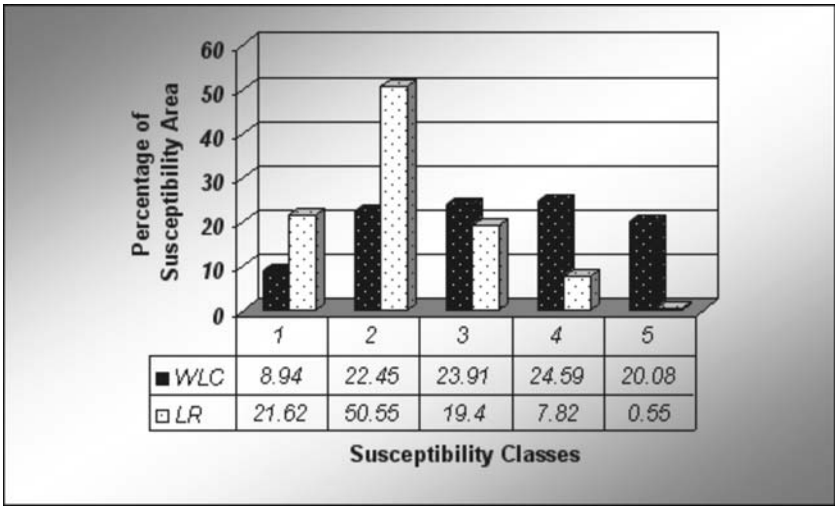


Fig. 7 Relative distribution of the susceptibility classes constructed by two susceptibility assessment model

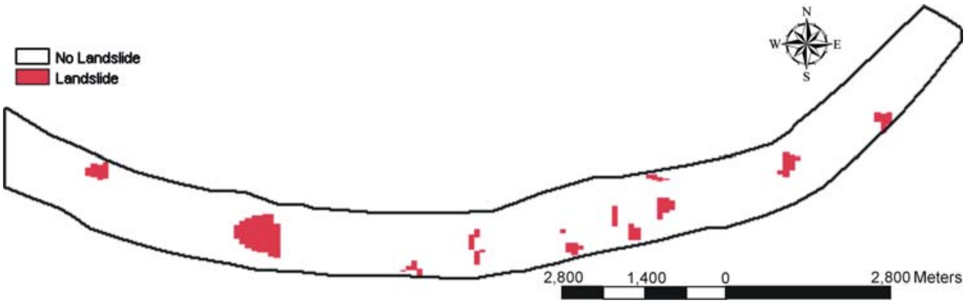


Fig. 8 Landslide location map

decades, such maps have been prepared using GIS-based qualitative and quantitative assessment techniques. Many of the quantitative techniques exist to analyse the relationship between landslides and their triggering parameters. Logistic regression and weighted linear combination methods are two of them. In order to use the logistic regression method for realizing a landslide susceptibility mapping, a reliable landslide inventory defining the type and activity of all landslides as well as their spatial distribution are essential. However, landslide inventories are not very common, especially in Turkey. In the case of lack of landslide inventory map, expert opinion based methods can be used as well. For this purpose, weighted linear combination method may be a good choice because the method requires proper parameters collected from the field, and the obtained parameters are assessed using reliable mathematical approches. In this regard, the two mentioned methods are suggested to be used together for a given area and the obtained results must be comparable.

In this context, two types of results were examined in this study. The first was to find areas susceptible to landslide and the second was to compare the results obtained by logistic regression and weighted linear combination methods in view of their effectiveness and usefulness.

Two landslide susceptibility maps of the Arsin-Yomra towns, Trabzon, Northeastern Turkey were produced using the LR and WLC methods. According to the obtained results, more than 60% of the study area is threatened by a landslide occurrence. Especially, the eastern part of the study area is more susceptible than the western part. It is determined that weathering and steep slopes play important role in the occurrence of landslide in the study area. To validate the results, both susceptibility maps were matched with a landslide inventory map in which 13 landslide zones were identified. The results showed that the 47.4% of the landslide zones fall into the high and very high susceptibility classes in both the LR susceptibility map and the WLC susceptibility map. In the WLC map, there is no active landslide zone in the very low susceptibility class, whereas 7.69% of the active landslides fall into the same class in the LR map. Both maps gave almost similar results but with some differences in their details. The reason for the differences is considered to be the subjectivity of the strategy applied to weighted linear combination model and choosing the proper scores to construct the susceptibility classes. However, it is determined that the logistic regression and weighted linear combination models can be effectively used together for many landslide susceptibility assessments.

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