ORIGINAL ARTICLE

Remote sensing and GIS-based landslide susceptibility mapping using frequency ratio and analytical hierarchy methods in Rize province (NE Turkey)

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Abstract The northeast part of Turkey is prone to landslides because of the climatic conditions, as well as geologic and geomorphologic characteristics of the region. Especially, frequent landslides in the Rize province often result in significant damage to people and property. Therefore, in order to mitigate the damage from landslides and help the planners in selecting suitable locations for implementing development projects, especially in large areas, it is necessary to scientifically assess susceptible areas. In this study, the frequency ratio method and the analytical hierarchy process (AHP) were used to produce susceptibility maps. Especially, AHP gives best results because of allowing better structuring of various components, including both objective and subjective aspects and comparing them by a logical and thorough method, which involves a matrix-based pairwise comparison of the contribution of different factors for landslide. For this purpose, lithology, slope angle, slope aspect, land cover, distance to stream, drainage density, and distance to road were considered as landslide causal factors for the study area. The processing of multi-geodata sets was carried out in a raster GIS environment. Lithology was derived from the geological database and additional field studies; slope angle, slope aspect, distance to stream, distance to road and drainage density were invented from digital elevation models; land cover was produced from remote sensing imagery. In the end of study, the results of the analysis were verified using actual landslide location data. The validation results showed satisfactory agreement between the susceptibility map and the existing data on landslide locations.

Keywords Landslide · AHP · Statistical methods · Satellite imagery · Rize

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Introduction

Landslide is one of the most costly and damaging natural hazards of the world. Landslide hazard assessment is a method to evaluate the hazard where there is the potential for landslides. Landslide hazard assessment includes many terrain factors and complex processes (Dai et al. 2001).

There are new settlement areas at the society that growing up. However, while making selection of these areas to be required investigating in the point of natural hazards. Large numbers of casualties and huge economic losses have occurred in settlement areas that casually select and make no studies related to natural hazards. Therefore,

it is very important landslide hazard studies. Over the past 25 years, many governments and international research institutions across the world have invested considerable resources in assessing landslide susceptibilities and attempting to produce maps portraying their spatial distribution (Guzzetti et al. 1999, 2005, 2006; Chung and Fabbri 2003).

Natural hazards have been threatening people who live in the rough areas like East Black Sea region. The losses occurring because of natural hazards are indicators in this region. People live in the East Black Sea region look for settlement areas because of population increase. For selection of settlement areas or route of infrastructure systems are not make engineering works generally (Yalcin 2008). For this reason, many engineering problems have occurred. In this study, areas of susceptibilities from the point of landslides have been determined in Rize province. Landslide locations were identified in the Rize region from interpretation of aerial photographs, field surveys, and satellite images. For the landslide susceptibility analyses, a number of different methods have been utilized and suggested. The process of creating these maps involves several qualitative or quantitative approaches. Qualitative methods are subjective; they represent the susceptible levels in descriptive expressions, and depend on expert opinions. The most common types of qualitative methods basically use landslide inventories to recognize sites of comparable geological and geomorphologic characteristics that are susceptible to failure. Quantitative methods are based on numerical expressions of the relationship between controlling factors and the landslides (Lee et al. 2004; Komac 2006; Yalcin et al. 2011).

The aim of this study is to present a comparison between the landslide susceptibility mapping methods of frequency ratio (FR) and analytical hierarchy process (AHP), and determine which methods give results that are more accurate. For this, the occurrence of shallow landslides was detected in the study area by interpretation of field surveys and satellite imagery.

Lithology, slope, aspect, land cover, distance to stream, drainage density, and distance to road spatial databases were constructed for the landslide susceptibility analysis. This analysis can be carried out by applying the frequency ratio and analytical hierarchy process, with confirmation of the results.

Using GIS and remote sensing (RS) as the basic analysis tools for landslide susceptibility mapping can be effective for management and manipulation of spatial data, together with some reasonable models for the analysis. The researchers concluded that RS and GIS-based methodologies are suitable for the development of landslide hazard maps.

Description of the study area

The study area, in Rize province, consisted of $\sim 2,700$ km^2 located between $39°15'$ and $40°15'$ west–east longitudes and $41°8'$ and $40°30'$ north–south latitudes in the middle of Eastern Black Sea region (Fig. 1).

The Rize area, located in the eastern part of the Black Sea region, is prone to landslides because of the climatic conditions, as well as geologic and geomorphologic characteristics of the region. As in previous years, there were many landslides in the region, due to the heavy rainfalls in those years and those landslides caused damage and human casualties. Rize is the rainiest city in Turkey. Total annual precipitation is over 2,300 mm (Table 1), and precipitation is equally distributed in each month (Fig. 2).

Rainfall, particularly the interception process, also appears to be a major influence as a 'trigger' for landslides. The role of the rainfall on the process of landslides is highly complex. Two aspects require a careful attention: those are drainages prior to construction (i.e., under natural conditions) and after settlement on the area and clearing the land covers for tea agriculture. It is widely acknowledged that the urbanization and tea gardens of a region dramatically alter interception patterns. Under natural conditions, vegetation would normally act as a protective barrier and the intercepted rainfall and water would be distributed through natural drainage channels. In terms of density of the cover, as it would be expected in a tropical region, sparsely vegetated slopes display faster erosion rates compared to the more densely vegetated areas. In addition to the surface (slope wash) erosion, deforestation results in an increase in water table levels and a subsequent reduction in shear strength of regolith mass, after prolonged and intense rainfall especially. Residential construction, modifications to the natural environment through vegetation cover destruction and the increase in concrete, paved areas create very different interception patterns. Invariably, less rainwater is intercepted, and the concrete surfaces promote channeled run-off. This situation can be exacerbated by the flow of sewage and other household wastewater, since the majority of tea gardens do not have infrastructure provision for the disposal of such wastes. The empirical findings indicate that duration and intensity of rainfalls are important, as heavy and prolonged rainfall has been associated with the increasing number of incidences of landslide events throughout the Ardesen region, especially in the tea gardens (Karsli et al. 2009).

In particular, Rize province suffered large economic losses. There is still a great danger of further landslides in the region. Therefore, it is very important to take necessary measures to protect the people from injury and the buildings from damage by carrying out detailed landslide
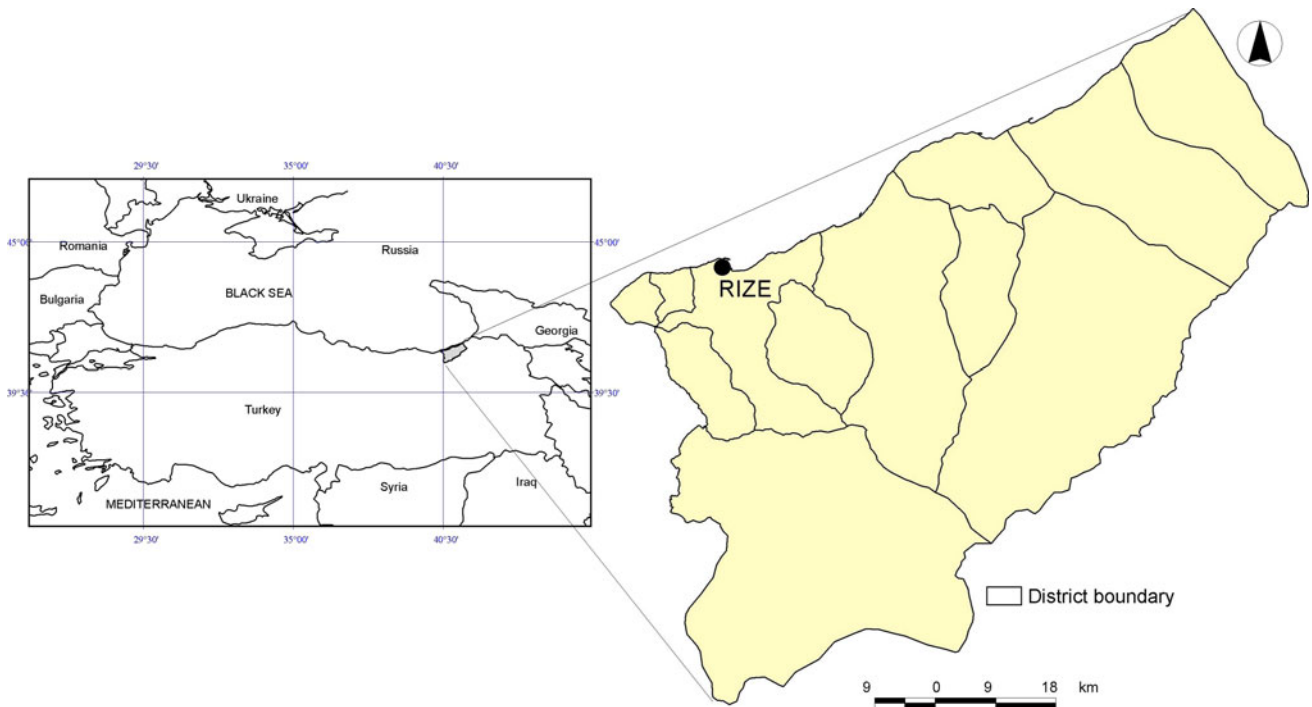
Fig. 1 Location map of the study area

Table 1 Monthly average precipitation versus temperature data

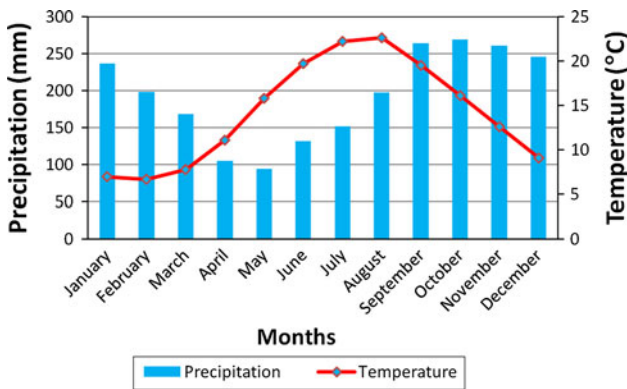| Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Precipitation (mm)	236.8	198.1	168.6	105.0	94.3	131.9	151.4	197.1	264.2	269.1	260.8	245.9
Temperature (°C)	7.0	6.7	7.8	11.1	15.8	19.7	22.2	22.6	19.5	16.1	12.6	9.1

Fig. 2 Monthly average precipitation versus temperature graphic

research that will determine the dangerous locations for potential landslides in the region.

Methodology

The study began with the preparation of a landslide inventory map based on extensive fieldwork, a previous inventory map, and satellite images. It is very important to determine the location and area of the landslide correctly when preparing the landslide susceptibility maps. Landslide inventory maps can be prepared in different formats according to the size of the area, the data obtained from the land, the quality of this data and the scale of the study. These maps can be produced by gathering the information related with the landslides or by analyzing the data from remote sensing. By testing the results, obtained by evaluating the satellite imagery, with land controls, it was determined that the data obtained matched with the data of the land. The landslide area and related data for the properties of landslide were obtained quickly and accurately by evaluating the satellite imageries.

Frequency ratio methods are based on the observed associations between distribution of landslides and each landslide-related factor, to expose the correlation between landslide locations and the factors in the study area. Using the frequency ratio model, the spatial associations between landslide location and each of the factors contributing landslide occurrence were derived. The frequency is calculated from the analysis of the relation between landslides

and the attributed factors. Therefore, the frequency ratios of each factor's type or range were calculated from their relationship with landslide events as shown in Table 2. The frequency ratio was calculated for sub-criteria of parameter, and then the frequency ratios were summed to calculate the landslide susceptibility index (LSI) (Eq. 1) (Lee and Talib 2005).

$$LSI = Fr_1 + Fr_2 + Fr_3 + \cdots\cdots + Fr_n \qquad (1)$$

where, Fr is rating of each factor's type or range.

Table 2 Frequency ratio values of the landslide-conditioning parameters

Parameter	Classes	% of total area (*a*)	% of landslide area (*b*)	Frequency ratio (*b/a*)
Geology	Alv	0.98	0.95	0.97
	Pl	0.16	0.00	0.00
	Gr	44.03	13.13	0.30
	An	43.77	59.45	1.36
	Da	8.98	16.71	1.86
	Kn	1.91	9.76	5.11
	Dy	0.18	0.00	0.00
Slope (%)	0–10	4.50	4.25	0.95
	10–20	2.81	10.40	3.70
	20–30	7.36	22.91	3.11
	30–40	12.15	21.54	1.77
	40–50	15.75	15.89	1.01
	50–60	15.75	10.23	0.65
	>60	41.68	14.78	0.35
Aspect	Flat	3.81	3.84	1.01
	North	15.09	17.89	1.19
	Northeast	12.65	13.27	1.05
	East	10.57	8.85	0.84
	Southeast	8.18	5.48	0.67
	South	9.88	7.70	0.78
	Southwest	12.00	10.15	0.85
	West	13.78	16.20	1.18
	Northwest	14.03	16.62	1.18
Elevation (m)	0–500	21.11	46.99	2.23
	500–1,000	16.70	20.04	1.20
	1,000–1,500	14.42	22.68	1.57
	1,500–2,000	12.44	3.22	0.26
	2,000–2,500	13.88	1.33	0.10
	2,500–3,000	16.94	3.92	0.23
	3,000–3,500	4.48	1.81	0.40
	3,500–4,000	0.04	0.00	0.00
Land cover	Tea	16.17	39.74	2.46
	Deciduous	34.86	40.93	1.17
	Coniferous	10.31	4.73	0.46
	Rocky	12.11	3.67	0.30
	Pasture	19.25	7.59	0.39
	Agriculture	3.26	1.95	0.60
	Settlement	1.93	0.99	0.51
The distance to stream (m)	0–25	44.53	46.10	1.04
	25–50	46.76	51.04	1.09
	50–75	8.02	2.86	0.36
The distance to road (m)	0–15	0.50	0.49	0.98
	15–30	0.50	0.51	1.02

According to the frequency ratio method, the ratio is that of the area where the landslide occurred, to the total area, so that a value of 1 is an average value. If the value is >1, it means the percentage of the landslide is higher than the area and refers to a higher correlation, whereas values lower than 1 mean a lower correlation (Yalcin et al. 2011).

AHP is a multi-objective, multi-criteria, decision-making approach, which enables the user to arrive at a scale of preference drawn from a set of alternatives. AHP gained wide application in site selection, suitability analysis, regional planning, and landslide susceptibility analysis (Ayalew et al. 2005). To apply this approach, it is necessary to break a complex unstructured problem down into its component factors; arrange these factors in a hierarchic order; assign numerical values to subjective judgements on the relative importance of each factor; and synthesize the judgements to determine the priorities to be assigned to these factors (Saaty and Vargas 2001).

The pairwise comparison matrix was created by making dual comparisons made in this context. The weights are calculated from the pairwise comparison matrix undertaking an eigenvalues and eigenvectors calculation. It has been demonstrated that the eigenvector corresponding to the largest eigenvalue of the matrix provides the relative priorities of the factors, i.e., if one factor has preference, its eigenvector component is larger than that of the other. The components of the eigenvector sum to unity. Thus, a vector of weights is obtained, which reflects the relative importance of the various factors from the matrix of paired comparisons (Yalcin et al. 2011).

In AHP, an index of consistency, known as the consistency ratio (CR), is used to indicate the probability that the matrix judgments were randomly generated (Saaty 1977).

$$CR = CI/RI \tag{2}$$

where RI is the average of the resulting consistency index depending on the order of the matrix given by Saaty (1977) and CI is the consistency index and can be expressed as

$$CI = (\lambda_{max} - n)/(n - 1) \tag{3}$$

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

For all the models, where the AHP was used, the CR (Consistency Ratio) was calculated. If the CR values were >0.1, the models were automatically discarded. Using a weighted linear sum procedure (Voogd 1983) the acquired weights were used to calculate the landslide susceptibility models (Komac 2006).

Furthermore, the following seven possible landslide causing layers; lithology, slope, aspect, land cover, elevation, distance to stream, and distance to road were analyzed for landslide susceptibility mapping using the frequency ratio method and the analytical hierarchy process methods. Finally, the susceptibility maps produced from the two different methods were compared and evaluated using validation data sets.

Data layers

The landslide inventory map shows the area distribution of landslides and their properties. These maps show the noticeable landslides on the land. It is very important to determine the location and area of the landslide correctly when preparing the landslide susceptibility maps. In this study, the susceptibility mapping started with the preparation of an inventory map of 100 landslides from field studies (Fig. 3), a previous inventory map (Yalcin 2008), and satellite image analyses from Quickbird. Quickbird images were used in controlling some of the landslide areas determined during field studies. These landslide areas were extracted using manually digitizing method from satellite images. In addition, to confirm the practicality of producing two susceptibility maps, 40 active landslides zones were determined separately from the inventory map.

The main source of data related to the geomorphology of a land is determined by the lithologic properties of that land (Dai et al. 2001). The landslide event, a component of the geomorphological research, is related to the lithological characteristics of the land. It is extensively accepted that lithology significantly influences the occurrence of landslides, because lithological variations often lead to a difference in the strength and permeability of rocks and soils. The lithology maps of the study area were differentiated into seven lithological units (Fig. 4). Sedimentary rocks are
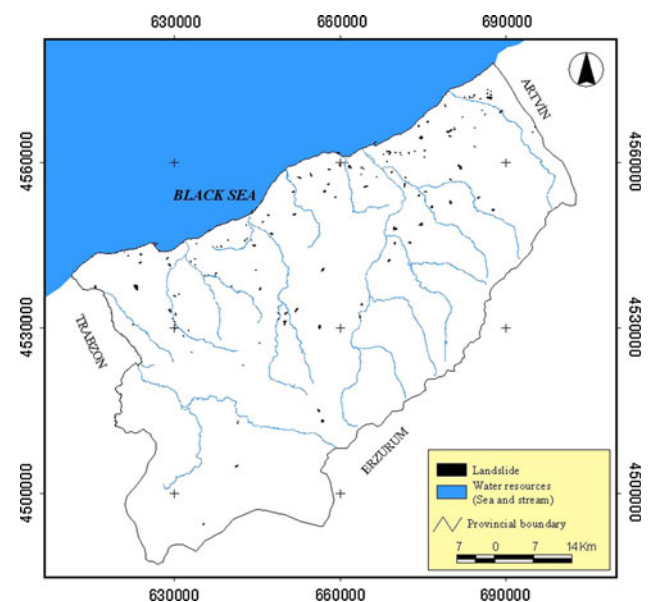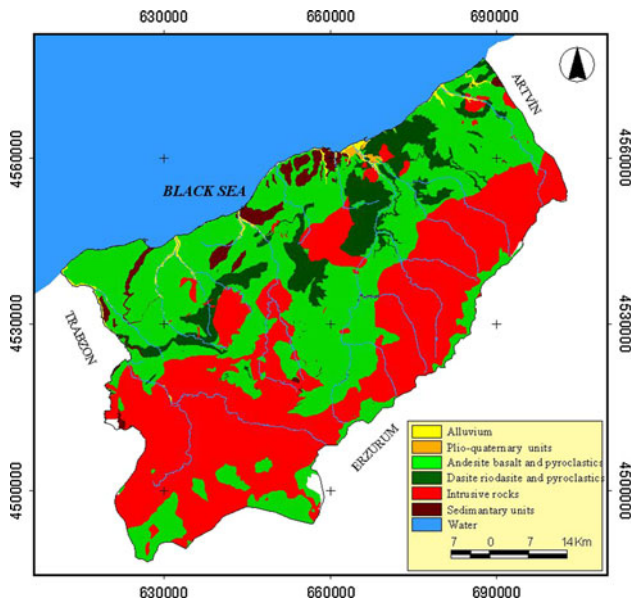

Fig. 3 Landslide inventory map

Fig. 4 Lithology map

fine-grained and contain feldspar and quartz fragments; sandstone intercalations are also observed. The units mainly consist of rather fine-grained sandstones, which contain marls and limestones in the lower levels with tuff breccia intercalations. Cementing material is represented by basalt and plagioclase pebbles, chlorite, and carbonate. These units show generally highly weathered degrees. Intrusive rocks (granite–granodiorite–diorite) occurring in the area are of Miocene age. The series described here are intersected by the basaltic and andesitic intrusive. It should be noted that the same features prevail throughout the eastern Black-Sea region. Intrusive rocks show very different weathering degrees. Dacitic units—generally fine-grained and bedded—show better development as compared to the other units of the lower dacitic series. They occur as a cement consisting of quartz, alkali feldspar and plagioclase. Within this cement, phenocrysts of plagioclase, alkali feldspar, and corroded quartz are present. These rocks are strongly kaolinized, sericitized, silicified and calcitized; chloritization, however, is poor. Dasitic units show generally very high weathered degrees. Andesite units, andesite sills and dykes are encountered in the area under investigation; these consist of a groundmass containing plagioclase phenocrysts, plagioclase and dark-colored minerals. On the surface, andesitescan be found in a restricted stratigraphic level between the lower dacitic series and the purple tuff. The basic units consist mainly of basalt, andesite, spilitic lava and their pyroclasts, sandstones and limestone intercalations. They overlie unconformably the lower dacitic series. It should, however, be noted that the surface of the unconformity does not show any sharp undulations. In the area under study, the basal

part of the upper basic series consists of purple tuff and basalts, andesitic breccia, red-colored limestones, basalts and marl-tuff breccia-limestone-sandstone units. Andesitic units show generally very high weathered degrees. So, all weathered lithological units affected to landslides. As a result of the aerial distributions analysis performed according to the lithological units, most landslides (59.45%) are located within andesite and pyroclastics rocks (Table 2).

The major parameter of the slope stability analysis is the slope angle (Lee and Min 2001) and because the slope angle is directly related to the landslides, it is frequently used in preparing landslide susceptibility maps (Yalcin and Bulut 2007). The slope map of the study area was divided into seven slope categories (Fig. 5). ArcGIS 9.2 analysis was performed to discover in which slope group the landslide happened and the rate of occurrence was observed. The landslide percentage in each slope group class is determined as a percentage of slopes. The result indicates that most of landslides (22.91%) occur when the percentage of the slope 20–30% (Table 2).

Aspect is also considered an important factor in preparing landslide susceptibility maps (Cevik and Topal 2003; Galli et al. 2008). Aspect associated parameters such as exposure to sunlight, drying winds, rainfall (degree of saturation), and discontinuities may control the occurrence of landslides (Komac 2006). The association between aspect and landslide is shown with aspect maps (Fig. 5). Aspect regions are classified in nine categories and the percentage of landslides, which occurred in each aspect class (Table 2). As a result of the aerial distributions analysis performed according to the aspect, most landslides (17.89%) are located within north aspect.

Like slope and aspect, elevation is another, very frequently used, parameter in landslide susceptibility studies. An elevation map portrays areas with different relative relief. Landslides may form in certain relief ranges (Dai et al. 2001; Cevik and Topal 2003). The elevation map of the study area (Fig. 5) was divided into eight elevation classes and the study area reveals that elevation ranges from 0 to 3,500 m above mean sea level. The result indicates that most of landslides (46.99%) occur when elevation ranges from 0 to 500 m (Table 2).

Land cover acts as a shelter and reduces the susceptibility of soil erosion, landslides and the get water on action of the precipitation. Several researchers (Reis and Yomralioglu 2006; Yalcin 2007) have emphasized the importance of land cover on slope stabilities. In this study, a single date image of Landsat ETM+ (Path 173; Row: 32) on October 19, 2000 was used to generate the land cover types. Using the image, after extracting an application area of approximately 120 × 90 km covering the administrative boundaries of Rize province, other studies, as required,

Fig. 5 a Elevation map,
b aspect map and **c** slope map
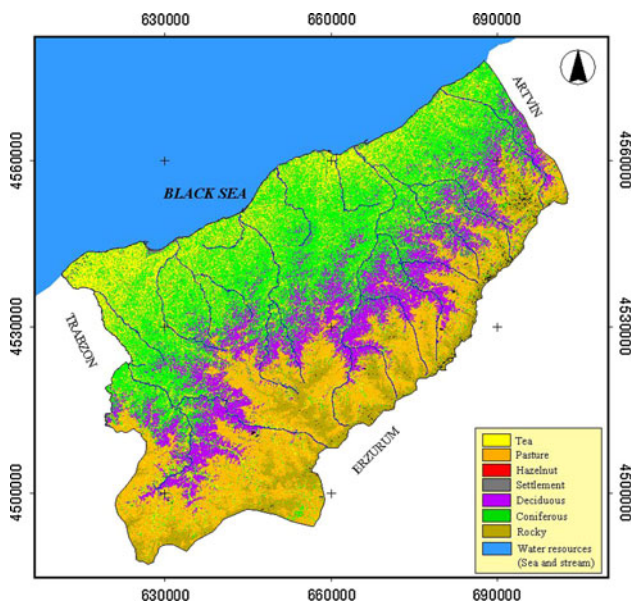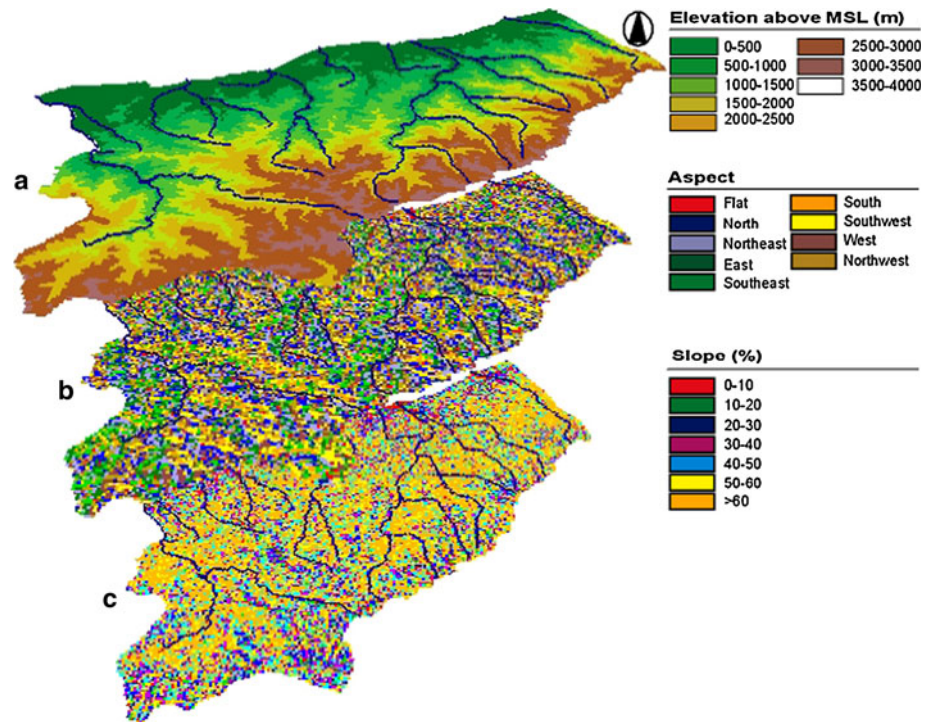

Fig. 6 Land cover map

Fig. 7 Distance to stream map

were implemented on this area. The study area was divided into seven land cover classes (Fig. 6) and is mostly covered by tea and deciduous areas. Landslides are largely observed in deciduous and tea areas (Table 2).

Important parameter that controls the stability of a slope is the saturation degree of the material on the slope. Distance to stream is one of the controlling factors for the stability of a slope. Streams may negatively influence stability by eroding the slopes or by saturating the lower
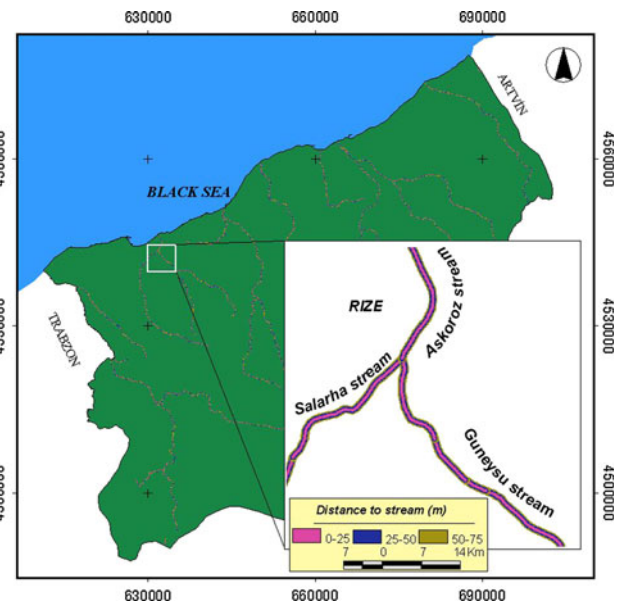
part of material until the water level increases (Saha et al. 2002; Yalcin 2008). The study area was divided into three different buffer ranges as 0–25, 25–50, and 50–75 (Fig. 7). Landslides are basically observed in 0–25 and 25–50 m buffers' areas (Table 2).

Like to the effect of the distance to streams, landslides may occur on the road and on the side of the slopes affected by roads (Yalcin 2008). The study area was divided into two different buffers categorized to designate the

influence of the road on the slope stability (Fig. 8). The landslide percentage distribution was determined according to the buffer zones by comparing the map of the distance to the road and the landslide inventory (Table 2).

Landslide susceptibility analyses

In this study, the landslide susceptibility analyses were implemented using the methods of frequency ratio and analytical hierarchy process. The frequency ratio is the ratio of the area where landslides occurred in the total study area, and also, the ratio of the probabilities of a landslide occurrence to a non-occurrence for a given attribute (Lee and Talib 2005). The frequency ratio was calculated for sub-criteria of parameters, and then the frequency ratios were summed to calculate the LSI (Eq. 1) (Lee and Talib 2005).

The frequency ratios of all parameters were shown Table 2. On completion of the analyses the frequency ratio of each layer's classes was determined, and a landslide susceptibility map (Fig. 9) was produced by the LSI map using Eq 1.

In AHP technique, firstly, the effects of each parameter to the susceptibility of landslides relative to each other were determined by dual evaluation in determining the preferences in the effects of the parameters to the landslide susceptibility maps. Normally, the determination of the values of the parameters relative to each other is a situation that depends on the choices of the decision-maker. However, in this study, both the comparison of the parameters relative to each other and the determination of the decision alternatives, namely the effect values of the sub-criteria of
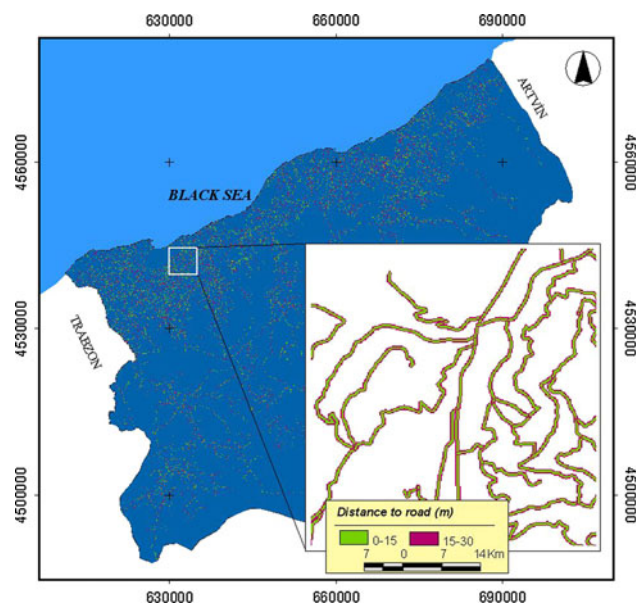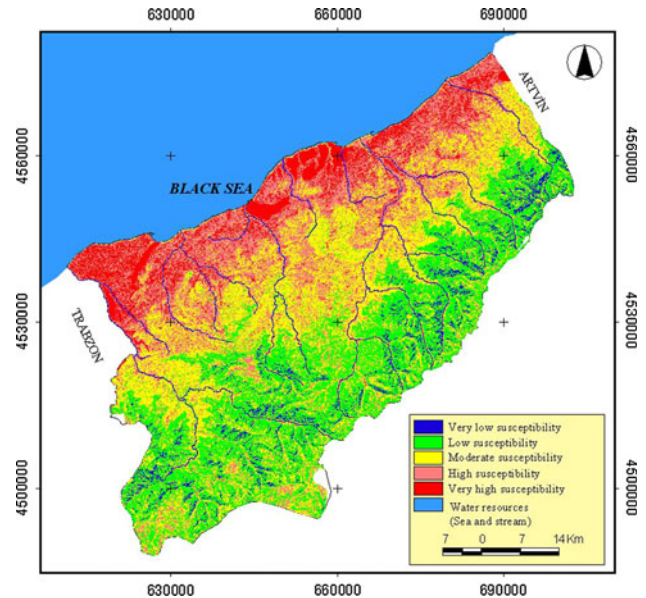

Fig. 9 The landslide susceptibility map produced by FR

the parameters (weight), were based on the comparison of landslide inventory maps constructed using satellite images and field surveys with the other data layers (Yalcin 2008). Consequently, the weight values were determined accurately for the real land data (Table 3). As a result of the AHP analyses, the landslide susceptibility map was produced for Rize province (Fig. 10). In the study, lithology and slope are found to be important parameters for the study area, whereas distance to streams and roads were of lesser importance.

Results and comparative

The landslide susceptibility maps were prepared using two different weighting procedures in a RS and GIS-based approach. The area and percentage distribution of the susceptibility classes in the study area were determined as a result of the two different methods. To test the reliability of the landslide susceptibility maps produced by the frequency ratio and AHP, a landslide activity map of 40 active zones of recent landslides and the susceptibility maps were compared. In these comparisons, the area on the landslide activity map, which shows where the landslides occurred, is matched with the landslide susceptibility maps. Then, the distribution of the actual landslide areas is determined according to the landslide susceptibility zones.
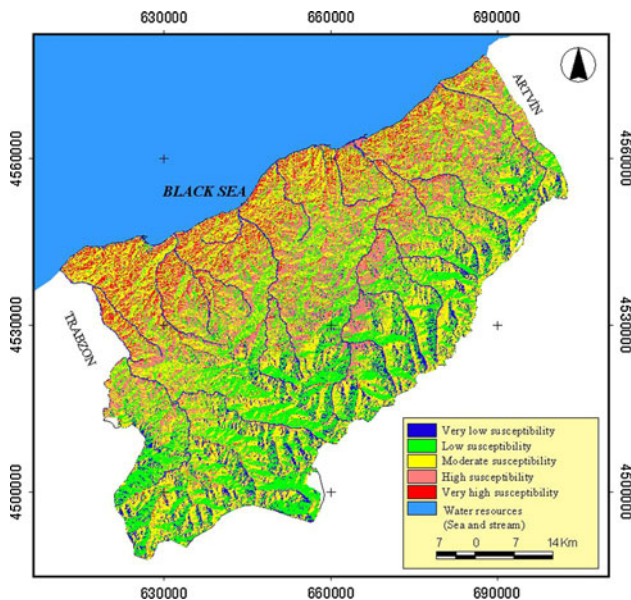
The landslide susceptibility map has a continuous scale of numerical values and there is a need to separate these values into susceptibility classes. There are several mathematical methods for the classification susceptibility degrees (Ayalew et al. 2004). The standard deviation classifier is

Fig. 8 Distance to road map

Table 3 Pair-wise comparison matrix, factor weights and consistency ratio of the data layer

Factors	1	2	3	4	5	6	7	8	9	Weights
(1) Alv	1									0.076
(2) Pl	1/3	1								0.030
(3) Gr	1/2	3	1							0.055
(4) An	3	5	4	1						0.130
(5) Da	4	6	5	3	1					0.190
(6) Kn	7	9	7	8	6	1				0.483
(7) Dy	1/3	1	1/2	1/3	1/4	1/9	1			0.035
(1) 0–10	1									0.070
(2) 10–20	7	1								0.382
(3) 20–30	7	1/2	1							0.280
(4) 30–40	2	1/4	1/3	1						0.118
(5) 40–50	1	1/5	1/4	1/2	1					0.075
(6) 50–60	1/3	1/7	1/6	1/3	1/2	1				0.044
(7) >60	1/2	1/8	1/7	1/4	1/3	1/2	1			0.032
(1) Flat	1									0.054
(2) North	2	1								0.187
(3) Northeast	1	1/2	1							0.054
(4) East	3	1/4	3	1						0.085
(5) Southeast	4	1/5	4	1/2	1					0.074
(6) South	3	1/4	3	1	2	1				0.085
(7) Southwest	3	1/4	3	1	2	1	1			0.085
(8) West	2	1	2	3	4	3	3	1		0.187
(9) Northwest	2	1	2	3	4	3	3	1	1	0.187
(1) Tea	1									0.418
(2) Deciduous	1/3	1								0.226
(3) Coniferous	1/6	1/4	1							0.065
(4) Rocky	1/7	1/5	1/2	1						0.041
(5) Pasture	1/7	1/5	1/2	1	1					0.041
(6) Agriculture	1/5	1/3	2	3	3	1				0.104
(7) Settlement	1/5	1/3	2	3	3	1	1			0.104
(1) 0–500	1									0.367
(2) 500–1,000	1/4	1								0.162
(3) 1,000–1,500	1/3	2	1							0.203
(4) 1,500–2,000	1/6	1/4	1/5	1						0.061
(5) 2,000–2,500	1/7	1/5	1/6	1/3	1					0.032
(6) 2,500–3,000	1/6	1/4	1/5	1	3	1				0.058
(7) 3,000–3,500	1/5	1/3	1/2	2	4	2	1			0.093
(8) 3,500–4,000	1/9	1/6	1/7	1/4	1/2	1/3	1/4	1		0.023
(1) 0–25	1									0.429
(2) 25–50	1	1								0.429
(3) 50–75	1/3	1/3	1							0.143
(1) 0–25	1									0.500
(2) 25–50	1	1								0.500
Data layers										
(1) Lithology	1									0.231
(2) Slope	2	1								0.345
(3) Elevation	1/4	1/5	1							0.077
(4) Land cover	1/2	1/3	2	1						0.132

Table 3 continued

Factors	1	2	3	4	5	6	7	8	9	Weights
(5) Aspect	1/2	1/3	3	1	1					0.151
(6) Distance to stream	1/6	1/7	1/3	1/4	1/5	1				0.038
(7) Distance to road	1/7	1/8	1/4	1/5	1/6	1/2	1			0.027

Fig. 10 The landslide susceptibility map produced by AHP

proposed when the histogram of data values exhibits a normal distribution (Suzen and Doyuran 2004). As a result, the standard deviation classifier was used since the data values in the landslide susceptibility maps obtained using the frequency ratio and AHP show a normal distribution.

According to the landslide susceptibility map produced from the frequency ratio method, 3.52% of the total area is found to be of very low landslide susceptibility. Low, moderate, and high susceptible zones represent 30.59, 29.81 and 26.75% of the total area, respectively. The very high landslide susceptibility area is 9.34% of the total study area.

The landslide susceptibility map generated with AHP, which included 7.14% of total area is determined to be of very low landslide susceptibility. Low and moderate susceptible zones make up 27.46 and 37.27% of the total area, respectively. The high and very high susceptible zones values are 21.73 and 6.39%.

Conclusion

In this paper, two different weighting procedures to study landslide susceptibility assessment applied to Rize province was presented. Two of the available approaches, for landslide susceptibility mapping, used in this study, were FR and AHP. To confirm the practicality of the results, the two susceptibility maps were compared with 40 active landslide zones. The result was that the active landslide zones coincided with a high percentage for the high and very high susceptibility class in the FR and AHP maps, as around 73 and 70%, respectively. Thus it can be concluded, that when field conditions and characteristics are accurately determined by professional expertise, the FR method gives better results in the study area.

Frequency ratio methods are based on the observed associations between distribution of landslides and each landslide-related factor, to expose the correlation between landslide locations and the factors in the study area. Using the frequency ratio model, the spatial associations between landslide location and each of the factors contributing landslide occurrence were derived. In AHP method, the weighting of selected factors is done very logical and the parameters could be arranged with their priorities and importance. Besides, assessment of classes is very significant, that could repeat its stages several times until to give a better result. Therefore, in this case, the derived model will be better for the reason of existence of more parameter. The study will be valuable for assessing landslide susceptibility and showing their spatial distribution, using a GIS database, and in addition, will be a great help in planning land use and in slope management such as landslide prone-areas.

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