

Adaptation and comparison of expert opinion to analytical hierarchy process for landslide susceptibility mapping

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Abstract In this study, an attempt was made to re-evaluate and compare landslide susceptibility in a landslide-prone area in the West Black Sea Region of Turkey, using expert opinion and the analytical hierarchy process (AHP). In order to compare the results with a landslide susceptibility study undertaken previously in the same region using the artificial neural network (ANN) method, slope angle, slope aspect, topographical elevation, topographical shape, water conditions and vegetation cover parameters were taken into consideration. Experts were asked to rate their pairwise importance and their feedback was used in the AHP to produce a landslide susceptibility map of the study region. Its validity was tested using relation value (r_{ij}) and the areal frequency distribution of the actual landslides in the area. The results were satisfactory and similar to those achieved in the previous ANN study. It is concluded that AHP can be a useful methodology in landslide susceptibility assessment.

Keywords Analytical hierarchy process · Expert opinion · Landslide · Landslide susceptibility · West Black Sea Region

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Résumé Des experts ont été invités à évaluer d'euxpart l'importance de ces paramètres et leur rétroaction a été employée dans l'AHP pour produire une carte de susceptibilité d'éboulement de la région étudiée. Sa validité a été examinée utilisant la valeur de relation (r_{ij}) et la distribution de fréquence régionale des éboulements réels dans le secteur. Les résultats étaient satisfaisants et semblables à ceux réalisés dans l'étude précédente. On conclut que le PHA peut être une méthodologie utile dans l'évaluation de susceptibilité d'éboulement.

Mots clés Processus analytique de l'hierarchie · Opinion experte · Éboulement · Susceptibilité d'éboulement · Région Occidentale De la Mer Noire

Introduction

Although geoscientists in Turkey have emphasized the potential impacts and importance of natural hazards for a long time, the Kocaeli earthquake in 1999 (one of the most destructive in Turkey) may be considered the starting point of awareness about natural hazards and their consequences by the general public, local administrations and non-governmental organizations (NGOs). Thus, in the last decade the assessment of natural hazards has become a very important issue in Turkey. After the earthquakes, landslides are of the second greatest importance as regards casualties and losses. In addition to socio-economic effects, landslides also create very important environmental problems, such as decrease in river quality, loss of soil productivity and damage to forests as well as the vegetation cover, and hence are one of the most important natural and environmental issues in Turkey.

Turkish geoscientists have long been emphasizing the importance of studying natural hazards including the preparation of inventories and databases, multi-purpose maps etc. Different methodologies have been employed (e.g.: Ercanoglu and Gokceoglu 2002, 2004; Cevik and Topal 2003; Ercanoglu et al. 2004; Suzen and Doyuran 2004a, b; Yesilnacar and Topal 2005; Can et al. 2005; Ercanoglu 2005; Gokceoglu et al. 2005; Duman et al. 2006; Akgun and Bulut 2007; Tunusluoglu et al. 2007; Nefeslioglu et al. 2008). Frequently quantitative landslide assessment methods were used, such as statistical analyses (bi-variate and multivariate, logistic regression) and soft computing techniques (fuzzy logic and artificial neural networks) while other studies were based on landslide inventory mapping, e.g. Gokceoglu and Ercanoglu (2002), Duman et al. (2005). These studies are very important as they constitute the cornerstone of local and/or regional mitigation efforts and they may provide useful information for future works such as urban development and regional land-use planning projects.

Regardless of the landslide assessment method, the most important steps are the evaluation of the landslide characteristics and the construction of a landslide database. However, analysis of a cause and effect relationship is not always simple, as a landslide is seldom linked to a single cause (Aleotti and Chowdhury 1999). Additionally, geoscientists are always faced with uncertainty concerning the natural processes. Perhaps, this was the main idea behind Brabb's (1984) statement: "There is no agreement either on the methods for or on the scope of producing landslide susceptibility or hazard maps".

Since Brabb's work, probability theory has been used to take account of uncertainty problems and statistical methods have become particularly popular for assessing landslide susceptibility. Towards the end of the 1990s, artificial intelligence techniques such as fuzzy logic and artificial neural network methods (simulating human thinking) have increasingly been used for uncertainty-related problems and in mapping landslide susceptibility. Regardless of the particular methodology, experience and knowledge about the problem may play a very important role in finding a solution and may influence the reliability of the study. Not surprisingly, Brabb's (1984) statement is still valid despite the advances made by recent international scientific studies.

In view of the above limitations, this study was undertaken to re-evaluate landslide susceptibility in a landslide-prone area located in the western Black Sea region of Turkey. The methodology was based on two concepts: expert opinion and AHP. It was thought that utilization of expert opinion on landslide occurrence may provide useful information in solving the parametric interactions in the AHP. The results are compared with

the study of the same area undertaken by Ercanoglu (2005) who employed the artificial neural network (ANN) method to evaluate landslide susceptibility. In order to compare the landslide susceptibility maps produced by both studies, the same parameters and the landslide database used by Ercanoglu were also used in the present study, although other landslides have been recorded since his work.

Study area

The western Black Sea region (Fig. 1) is known as one of the most landslide-prone areas in Turkey. The study area covers 879.2 km² and is located 35 km SE of Bartın. The digital elevation model (DEM) obtained from the 1/25,000 scale topographical maps contained 1409798 (25 m × 25 m) pixels in 1,261 columns and 1,118 rows.

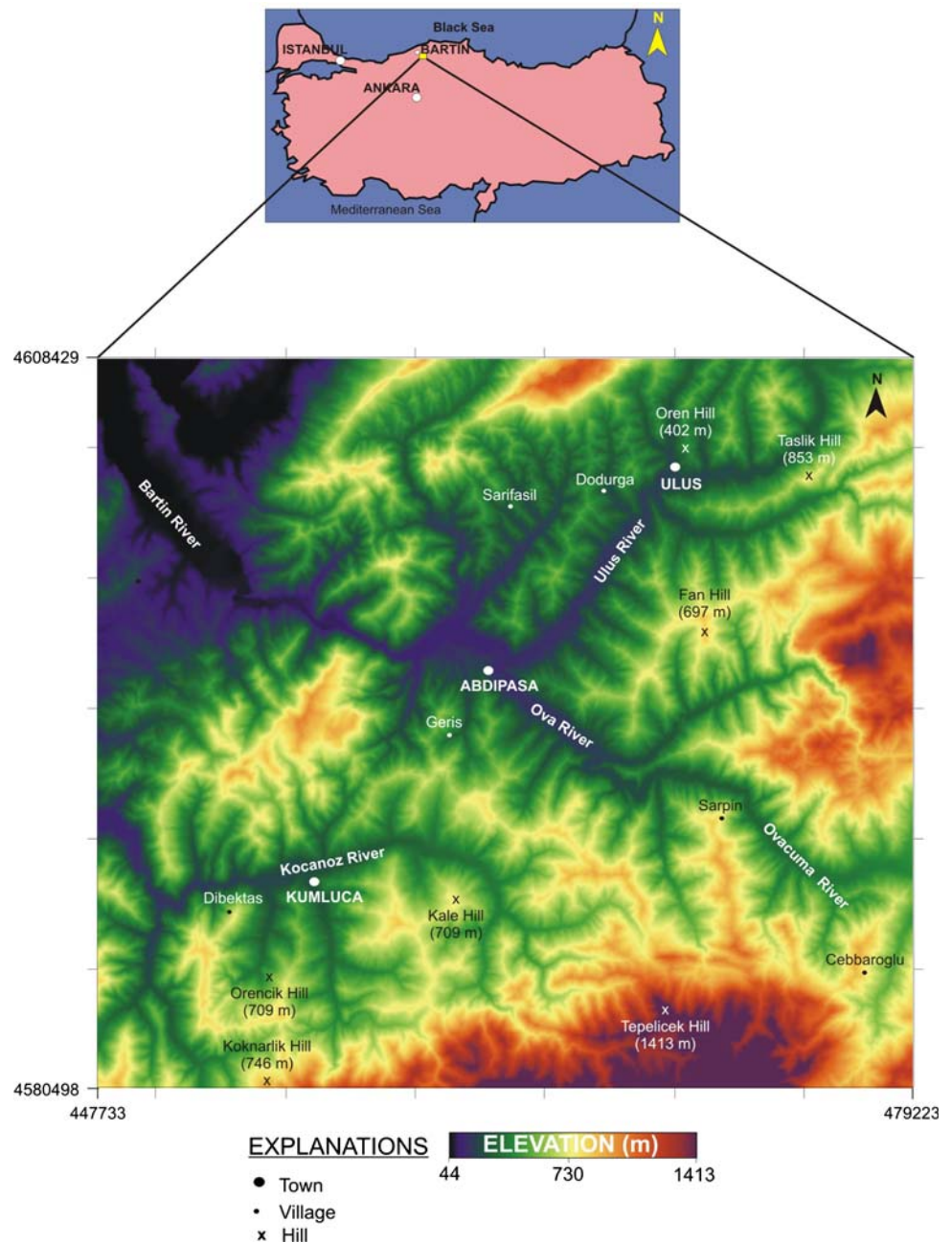
The study area ranges between 44 and 1,413 m asl; the highest point being Tepelicek Hill. Slope angles are up to 58°. The higher, steeper slopes are covered by dense forest (Fig. 2) while the lower more gentle slopes are generally farmed. Many streams with regular and/or irregular flow patterns form a dendritic drainage system in the region and are responsible for the formation of small valleys through channel erosion.

Geological characteristics

The study area is comprised of seven different lithological units (Fig. 3). The basement rocks are Palaeozoic in age. These acidic/basic rocks, dolomitic limestone and limestone are highly deformed such that the contact with other units is difficult to observe (Akartuna 1953; Deveciler 1986). These units are unconformably overlain by Mesozoic and Tertiary units. The Upper Jurassic–Lower Cretaceous Zonguldak Formation consists mainly of greyish to brownish limestone in which a high, steep gorge-like topography is present (Deveciler 1986; Ercanoglu 2003).

The Ulus Formation outcrops over approximately 65% of the study area, ie some 572 km² and is divided into two groups (Fig. 3). The Lower Cretaceous part is mainly composed of gravel, debris and claystone with no evidence of landslides, while the Upper Cretaceous part is a typical flysch sequence composed of sandstone, claystone and siltstone which is very susceptible to weathering. Limestone and quartzite outcrops are observed generally at higher elevations and often form the more weathering resistant part of the flysch while site observations found evidence of landslides within the weathered flysch layers (Ercanoglu

Fig. 1 Location map of the study area



2003; Ercanoglu et al. 2006). Although the geological term “flysch” generally implies “rock material”, the landslides in the study area occur in the weathered “soil materials” which cover the flysch layers. The soils contain different particle sizes ranging from fine grained clayey silt to blocks.

The Alaplı Formation of Lower Eocene age unconformably overlies the Uluş Formation and generally consists of clayey limestone. The Caycuma Formation, generally called “Eocene Flysch” in the region (Deveciler 1986) is dominantly limestone, sandstone and mudstone. Finally, the Quaternary alluvial deposits observed along the

river beds range from clay-sized particles to blocky, rock fragments (Deveciler 1986; Ercanoglu et al. 2006).

Landslides in the study area

All the landslides occur in the Uluş Formation of Upper Cretaceous age (see Fig. 3). Although landslide investigations were undertaken in the other lithological units, no landslides were observed or identified hence only the Uluş Formation was taken into consideration for the analyses. The landslide locations mapped and air photo

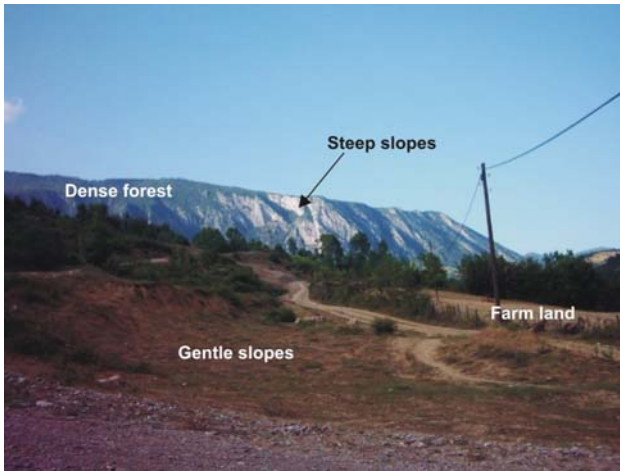
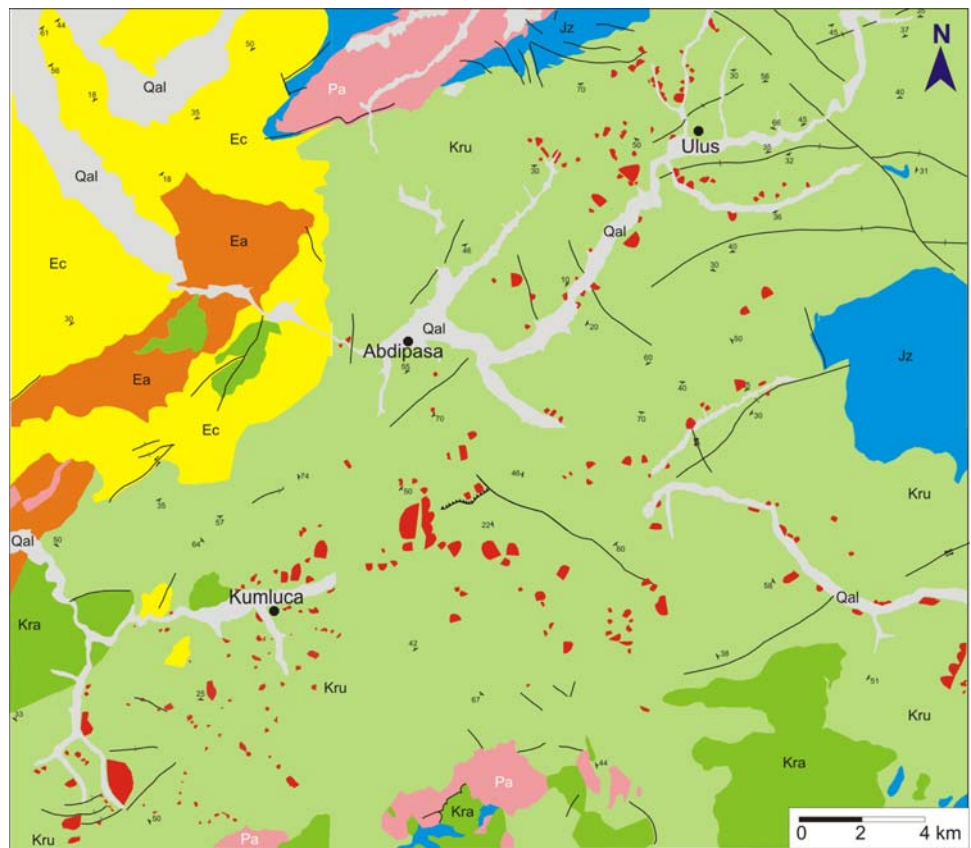


Fig. 2 A view of the steep and gentle slopes in the study area

interpretations made during 2004 and 2005 by Ercanoglu et al. (2006) were used.

A total of 317 landslides, covering approximately 2% of the Ulus Formation, were identified in the study area. Three different types of landslides were observed: rotational, flow and translational (based on the landslide classification system proposed by Varnes (1978); see Fig. 4). It was observed that the earth slumps (rotational slides) generally developed in the areas where the weathering zone was thicker (approximately 5–25 m) while the earth flows and translation slides were more abundant where the weathering extended to 2–9 m. Rotational slides and the earth flows were most common (173 and 133 respectively) while there were only 11 translational slides on the steep slopes where there was only a very thin layer of weathered flysch; for further information see Ercanoglu (2005).

Fig. 3 Simplified geological map of the study area (after Timur et al. 1997)



EXPLANATIONS

- Qal Quaternary (Alluvium)
- Ec Eocene (flysch features, limestone, sandstone, mudstone) (Caycuma Fm.)
- Ea Maastrichtian-L. Eocene (clayey limestone) (Alapii Fm.)
- Kru U. Cretaceous (flysch characteristics, sandstone, claystone, siltstone) (Ulus Fm.)
- Kra L. Cretaceous (gravel, debris, claystone) (Ulus Fm.)
- Jz U. Jurassic-L. Cretaceous (limestone, shelf deposits) (Zonguldak Fm.)
- Pa Paleozoic (acidic and basic rocks, dolomitic limestone, limestone)

- Mapped landslides
- Normal fault
- Strike slip fault
- Reverse fault
- Fault (type not defined)
- Fold axis
- Bedding plane orientation
- Town

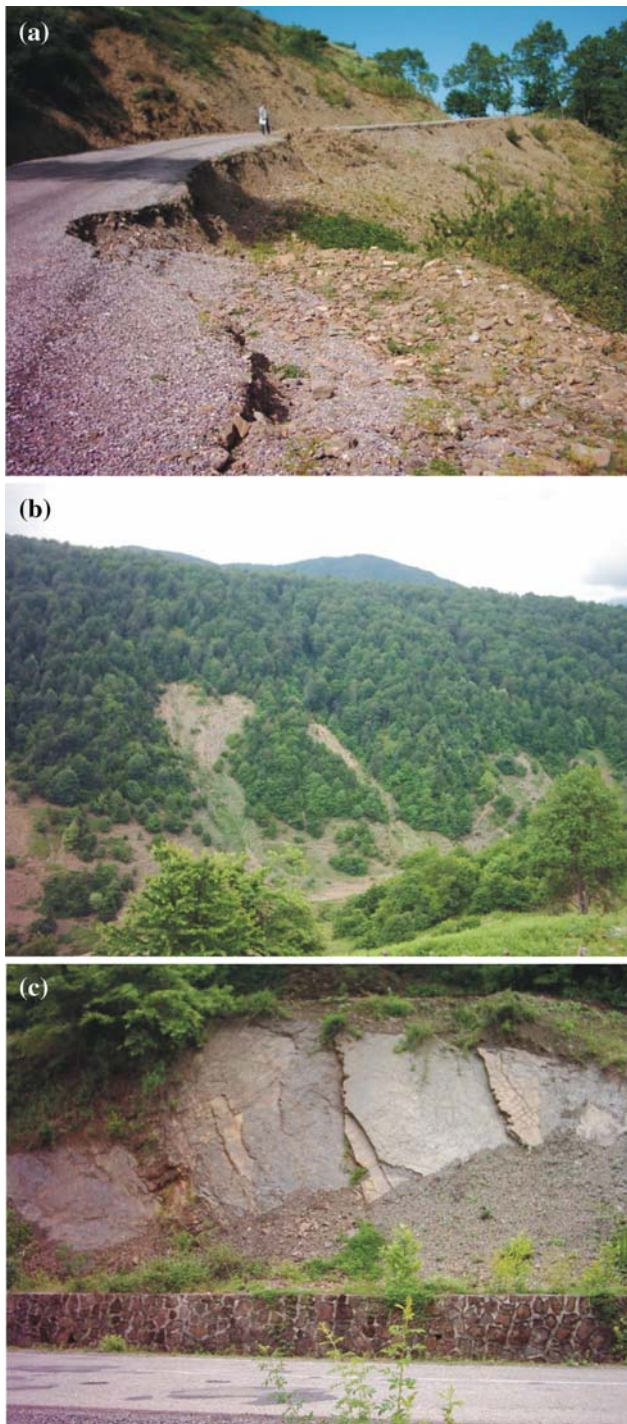


Fig. 4 Landslide types observed in the study area: **a** earth slump/rotational, **b** earth flow, and **c** earth slide/translational

Methodology

As discussed in detail by Carrara et al. (1991), Aleotti and Chowdhury (1999), Guzzetti et al. (1999), Ayalew et al. (2005), each landslide susceptibility assessment method has its advantages and disadvantages. Some older

approaches are never used, some have been refined and new methods are always being developed (Ayalew et al. 2005). For example, the heuristic approach, which is completely based on experience, knowledge and judgment is rarely used now and is generally considered to be too subjective. However, as pointed out by Van Westen (2000), subjectivity is not necessarily bad when it is based on the opinion of an expert. Indeed, as the selection of appropriate parameters is very important even when undertaking a GIS-based study (Ayalew et al. 2005), there is an indispensable need for experience, judgment and knowledge in establishing realistic criteria for a real geo-environment (Abdolmasov and Obradovic 1997).

For this reason, the present study attempted to combine the knowledge provided from the experts with the AHP method to evaluate landslide susceptibility in the selected region. The generalized flow-chart of the methodological approach is given in Fig. 5. At the first stage, the data obtained from Ercanoglu (2005) were uploaded, including landslide inventory and database, input parameter maps, and primary weight assigned parameter maps constructed with W_i values suggested by Van Westen (1997). The W_i value is expressed in the following equation:

$$W_i = [(N_{\text{pix}}(S_i)/N_{\text{pix}}(N_i))/(\sum N_{\text{pix}}(S_i)/\sum N_{\text{pix}}(N_i))] \quad (1)$$

where $N_{\text{pix}}(S_i)$ is the number of pixels exposed to landslides for a subgroup of a parameter, and $N_{\text{pix}}(N_i)$ is the total number of pixels for the related parameter.

For convenience, Fig. 6 (representing the parameter maps) and Table 1 (summarizing the distribution of landslides, W_i values, parameters and their sub-groups on landslide areas as well as on the study area) have been reproduced from Ercanoglu (2005).

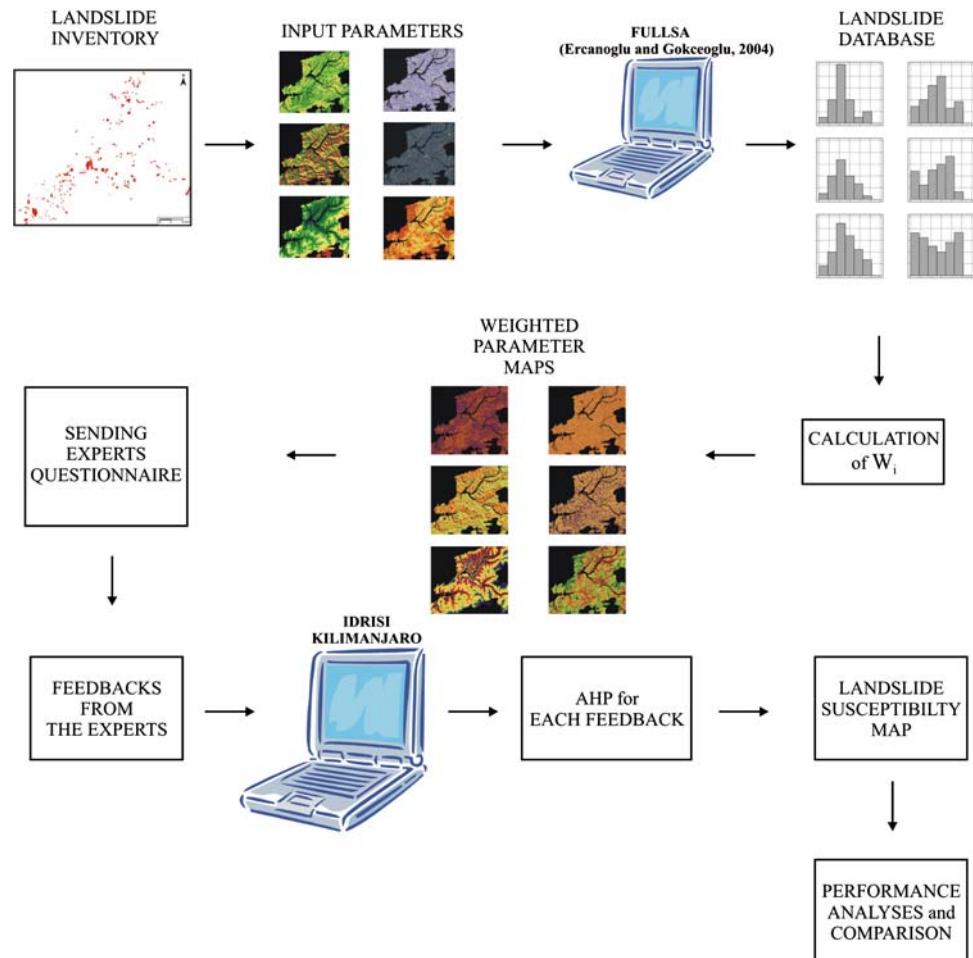
Slope angle, slope aspect, topographical elevation and topographical shape parameters were obtained directly from the DEM. In order to express water condition, a DEM-based wetness index, otherwise known as compound topographic index (CTI; Moore et al. 1988), was used to represent the spatial distribution of water flow across the study area. The wetness index represents a theoretical measure of the accumulation of flow at any point within a river basin and is calculated using the expression:

$$w = \ln(As / \tan \beta) \quad (2)$$

where w is the wetness index, As is the specific catchment area, and β is slope angle. Map Window (Release 2.7) (EMRC 2002) was used to calculate wetness index.

For the vegetation cover, normalized difference vegetation index (NDVI) values were derived from the advanced spaceborne thermal emission and reflection radiometer (ASTER) satellite image of the study area. NDVI is one of the slope-based vegetation index models widely used to generate vegetation indices. It is derived

Fig. 5 Generalized flow-chart of the methodology employed in the study



from reflectance measurements in the red and near-infrared portions of the electromagnetic spectrum, describing the relative amount of photosynthetically active green biomass present at the time of imagery. All the calculations and derivations were performed using Idrisi Kilimanjaro software (Eastman 2003).

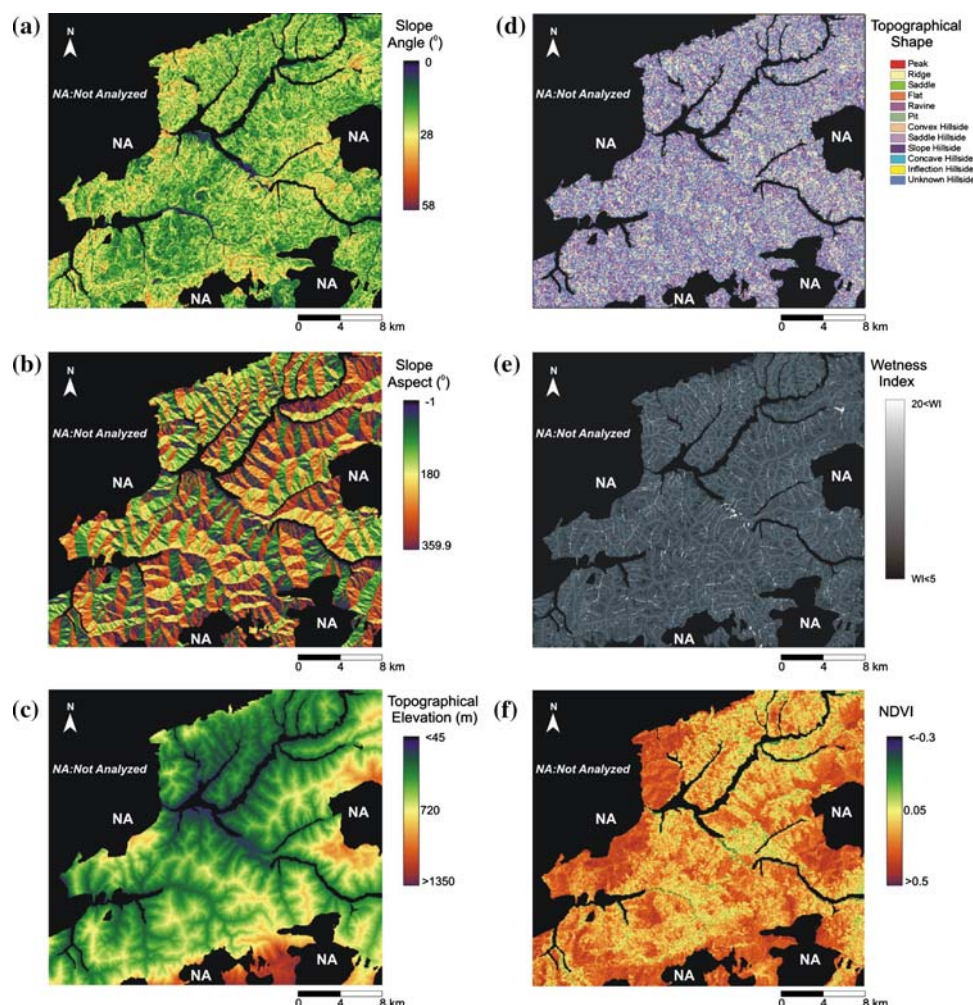
The second stage involved gathering the opinions of experts selected for their knowledge and experience about landslide concepts and their experience of landslides and their mechanisms, particularly in the West Black Sea Region of Turkey. It was not considered appropriate to ask experts from abroad as landslide characteristics vary from one region to another. The selected experts are professionals in geology and with academic backgrounds, particularly in engineering geology. They were asked to evaluate the pairwise comparison of the given parameters contributing to the regional landslide characteristics based on their experience and knowledge. This comparison was made based on the principles of the AHP method developed by Saaty (1977) which has been successfully employed in landslide susceptibility mapping by such workers as Barredo et al. (2000), Ayalew et al. (2005),

Komac (2006) and Akgun and Bulut (2007) using GIS-based multivariate statistics and logistic regression.

The AHP method is a multi-criteria decision-making process using the relative importance of the parameters contributing to the event to produce parameter weights and evaluates the consistency of pairwise comparison parameters (Barredo et al. 2000). The scale proposed by Saaty (1977) involves a rating system ranging between 1/9 and 9 (Table 2) where 1/9 is the least important and 9 the most important parametric effect. These values are placed in a matrix based on the parametric pairwise importance given in Table 2, in the form of row and column order.

The parametric pairwise ratings given by the seven selected experts are shown in Table 3. The Decision Support Wizard of Idrisi Kilimanjaro, including the WEIGHT and multi criteria evaluation (MCE) modules were used to evaluate landslide susceptibility. At this point, all of the matrices were fed into the computer using Idrisi Kilimanjaro's WEIGHT module; this is used to develop a set of relative weights for a group of parameters in a multi-criteria evaluation. The weights are developed by providing

Fig. 6 Parameter maps used in the study: **a** slope angle, **b** slope aspect, **c** topographical elevation, **d** topographical shape, **e** wetness index, **f** normalized difference vegetation index (after Ercanoglu 2005)



a series of pairwise comparisons of the relative importance of parameters to the suitability of pixels for the activity being evaluated. The parameters and their resulting weights can then be used as input for the MCE module (Eastman 2003). The weights generated by this module are produced by means of the principal eigenvector of the pairwise comparison matrix. The WEIGHT module uses each entry in the lower-left and its reciprocal (automatically completed by the module) in the upper-right of the matrix. The module also calculates the consistency ratio (CR), representing the degree of consistency. The consistency matrix shows how the individual ratings would have to be changed to be perfectly consistent with the best fit weightings achieved (Eastman 2003). CR values greater than 0.1 are considered an inconsistent rating and the matrix should be re-evaluated (Saaty 1977). As can be seen in Table 3 all the CR values were below 0.1 hence no re-evaluation was required.

The parameter weights calculated by the WEIGHT module are given in Table 4. In general the experts considered the most important parameter contributing to

landslide occurrence in the study area is the slope angle, followed by water conditions and topographical elevation (see Tables 3, 4).

The next stage was to run the MCE module in Decision Support Wizard. This attempts to combine a set of criteria to achieve a single composite basis for a decision for a specific purpose. In other words, multi-criteria evaluation is a process in which several criteria are evaluated in order to meet a specific objective (Eastman 2003). The MCE module requires a selection of one of the procedures provided by Idrisi Kilimanjaro such as Boolean intersection, weighted linear combination (WLC) or ordered weighted averaging (OWA). The WLC option involves multiplication of each parameter by its calculated weight and was selected as it had been successfully used in landslide assessment studies by Barredo et al. (2000) and Akgun and Bulut (2007). Finally, taking into consideration the seven experts' opinions, landslide susceptibility maps of the study area were produced (Fig. 7).

As can be seen from Fig. 7, the landslide susceptibility values range between 0 and 1. In order to highlight the

Table 1 Landslide database tabulating the characteristics of the landslides according to the considered parameters (after Ercanoglu 2005)

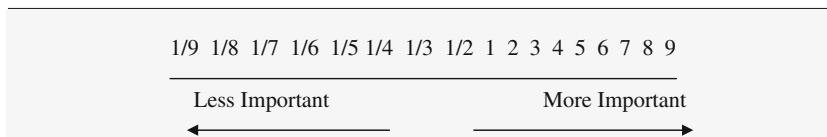
Group no.	Parameter	Number of landslided pixels	Number of pixels belonging parameter subgroup	Normalized W_i values
Slope angle, SA (°)				
1	$0 \leq SA \leq 10$	262	91929	0.12
2	$10 < SA \leq 20$	6510	340986	0.78
3	$20 < SA \leq 30$	7862	323523	1
4	$30 < SA \leq 40$	2430	103026	0.97
5	$40 < SA \leq 50$	494	61336	0.33
6	$50 < SA$	18	167	0.01
Slope aspect, SAS (°)				
1	$0 < SAS \leq 30$	1241	78576	0.50
2	$30 < SAS \leq 60$	964	76324	0.40
3	$60 < SAS \leq 90$	1455	78881	0.59
4	$90 < SAS \leq 120$	1873	80224	0.75
5	$120 < SAS \leq 150$	1483	70324	0.67
6	$150 < SAS \leq 180$	1592	69574	0.73
7	$180 < SAS \leq 210$	1480	62594	0.75
8	$210 < SAS \leq 240$	1890	60333	1
9	$240 < SAS \leq 270$	2114	79229	0.85
10	$270 < SAS \leq 300$	1483	90614	0.52
11	$300 < SAS \leq 330$	990	87761	0.36
12	$330 < SAS \leq 360$	1011	86533	0.37
Topographical elevation, TEL (m)				
1	$0 \leq TEL \leq 100$	0	463	0
2	$100 < TEL \leq 200$	680	38896	0.54
3	$200 < TEL \leq 300$	4012	123192	1
4	$300 < TEL \leq 400$	4940	181072	0.84
5	$400 < TEL \leq 500$	3395	179137	0.58
6	$500 < TEL \leq 600$	2951	152292	0.59
7	$600 < TEL \leq 700$	1351	105120	0.39
8	$700 < TEL \leq 800$	186	60343	0.09
9	$800 < TEL \leq 900$	61	34021	0.05
10	$900 < TEL$	0	46431	0
Topographical shape, TS				
1	Peak	1348	92375	0.55
2	Ridge	1474	88322	0.63
3	Saddle	98	3975	0.92
4	Flat	0	99178	0
5	Ravine	1577	87999	0.67
6	Pit	0	10897	0
7	Convex hillside	5885	220195	1
8	Saddle hillside	1392	77871	0.67
9	Slope hillside	60	4337	0.50
10	Concave hillside	5716	220446	0.97
11	Inflection hillside	26	5385	0.18
12	Unknown hillside	0	9987	0
Wetness index, WI				
1	$WI \leq 5$	328	178978	0.04
2	$5 < WI \leq 10$	1275	212532	0.14
3	$10 < WI \leq 15$	3461	185175	0.43
4	$15 < WI \leq 20$	8785	203194	1
5	$20 < WI$	3727	141088	0.61

Table 1 continued

Group no.	Parameter	Number of landslided pixels	Number of pixels belonging parameter subgroup	Normalized W_i values
Normalized difference vegetation Index, NDVI				
1	$NDVI \leq -0.3$	0	343	0
2	$-0.3 < NDVI \leq -0.2$	181	3237	1
3	$-0.2 < NDVI \leq -0.1$	353	8904	0.71
4	$-0.1 < NDVI \leq 0$	1399	41204	0.61
5	$0 < NDVI \leq 0.1$	3142	102051	0.55
6	$0.1 < NDVI \leq 0.2$	4556	168335	0.48
7	$0.2 < NDVI \leq 0.3$	4308	218542	0.35
8	$0.3 < NDVI \leq 0.4$	2999	254436	0.21
9	$0.4 < NDVI \leq 0.5$	638	122146	0.09
10	$0.5 < NDVI$	0	1769	0

Table 2 Scale of relative importance suggested by Saaty (1977)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed



most susceptible area, the landslide susceptibility was categorized into 5 different zones ranging from “very low” to “very high”, which correspond to “0–0.2” and “0.8–1”, respectively. When visually examined, the “very high” (black) and “high” (dark grey) landslide-prone areas generally coincide with the actual locations of the landslides.

Discussion and conclusions

The following results and conclusions can be drawn from the present study:

(1) Landslide susceptibility maps were produced by integrating expert opinion into AHP. The classifications used ranged from “very low” to “very high”. In spite of

- some differences, the experts generally assigned the landslide parameters similar weights (Table 5).
- (2) The maps show only the areal distribution of landslide susceptibility in the Ulus Formation. If the “very high” and “high” landslide susceptibility values in Table 5 are considered, it can be concluded that the area is very prone to landsliding as the mapped landslides cover only 2% of the study area whereas the maps suggest some 25% is at risk. This may indicate that the zones represent both actual and potential landslide areas.
- (3) In order to adopt the expert opinion into the AHP, standard forms of scale of relative importance suggested by Saaty (1977) were sent to the selected experts. Based on their feedback, the most important parameters for landslide occurrence were slope angle

Table 3 Experts' ratings on pairwise combination of the given parameters

	Slope angle	Slope aspect	Topographical elevation	Topographical shape	Water conditions	Vegetation cover
Expert 1 (CR = 0.04)						
Slope angle	1					
Slope aspect	1/7	1				
Topographical elevation	1/5	3	1			
Topographical shape	1/8	1/3	1/3	1		
Water conditions	1	5	5	5	1	
Vegetation cover	1/9	1/8	1/7	1/5	1/7	1
Expert 2 (CR = 0.06)						
Slope angle	1					
Slope aspect	1/5	1				
Topographical elevation	1/3	2	1			
Topographical shape	1/6	1/3	1/5	1		
Water conditions	1	4	3	5	1	
Vegetation cover	1/7	1/5	1/7	1/3	1/6	1
Expert 3 (CR = 0.03)						
Slope angle	1					
Slope aspect	1/3	1				
Topographical elevation	1/5	1/3	1			
Topographical shape	1/2	3	5	1		
Water conditions	1/2	3	5	1	1	
Vegetation cover	1/5	2	2	1/3	1/3	1
Expert 4 (CR = 0.05)						
Slope angle	1					
Slope aspect	1/9	1				
Topographical elevation	1/4	2	1			
Topographical shape	1/4	2	1	1		
Water conditions	2	4	2	2	1	
Vegetation cover	1/6	1	1/2	1/2	1/4	1
Expert 5 (CR = 0.07)						
Slope angle	1					
Slope aspect	1/5	1				
Topographical elevation	1	9	1			
Topographical shape	1/7	1/2	1/8	1		
Water conditions	1/2	7	1/4	9	1	
Vegetation cover	1/3	5	1/6	9	1	1
Expert 6 (CR = 0.08)						
Slope angle	1					
Slope aspect	1/8	1				
Topographical elevation	1	4	1			
Topographical shape	1/7	1/2	1/6	1		
Water conditions	1/2	5	4	5	1	
Vegetation cover	1/7	1/3	1/3	1	4	1
Expert 7 (CR = 0.05)						
Slope angle	1					
Slope aspect	1/8	1				
Topographical elevation	1/8	3	1			
Topographical shape	1/8	1/3	1/5	1		
Water conditions	1	9	8	5	1	
Vegetation cover	1/7	3	1	3	1/9	1

CR consistency ratio

Table 4 Calculated parameter weights based on the experts' opinion

	Slope angle	Slope aspect	Topographical elevation	Topographical shape	Water conditions	Vegetation cover
Expert 1	0.4248	0.0893	0.1175	0.0597	0.2801	0.0286
Expert 2	0.3409	0.0997	0.1653	0.0515	0.3124	0.0302
Expert 3	0.3453	0.0841	0.0441	0.2180	0.2180	0.0905
Expert 4	0.3588	0.0545	0.1106	0.1107	0.3077	0.0577
Expert 5	0.2630	0.0354	0.3956	0.0249	0.1520	0.1291
Expert 6	0.3505	0.0670	0.1941	0.0402	0.3024	0.0458
Expert 7	0.3720	0.0432	0.0827	0.0345	0.3951	0.0725

(av. 35%), water conditions (av. 28%) and topographical elevation (av. 16%). The importance of these parameters has been shown in other work, although their weights may vary from one region to another. It must also be appreciated that other parameters considered less important—or indeed parameters not used—in this study may be important elsewhere.

- (4) To check the validity of the landslide susceptibility maps produced, two different approaches were used: r_{ij} value (relation value or strength of relation) and areal frequency distribution of landslide susceptibility assigned pixels in the areas where landsliding has occurred. The FULLSA computer code was used; for details of the program and its modules see Ercanoglu and Gokceoglu (2004).

In the first approach, r_{ij} values for each landslide susceptibility map were calculated using the REL module of FULLSA which calculates a r_{ij} value, ranging between 0 and 1 and relatively represents the similarity of the considered data sets, based on the landslide inventory and the landslide susceptibility maps produced. Values of r_{ij} close to 0 indicate “dissimilarity” or “weak relation strength” while r_{ij} values approaching 1 represent “similarity” or a “strong relation” between the considered data sets. The results are shown Table 6, which indicates a good relationship (average r_{ij} value 0.896). The value of r_{ij} closest to 1 was obtained from Expert 2's ratings ($r_{ij} = 0.917$).

The second approach was the evaluation of the areal distribution of the landslide susceptibility classified pixels. The ASGN and DTB modules of FULLSA were used; the results (Table 7) are similar to that obtained from the r_{ij} values. Again, Expert 2's ratings gave the best results with approximately 73.2% of the landslide pixels in the area classified as of “very high” susceptibility. If the sums of the general average of very high and high susceptibility levels are considered together, 78.4% of the landslide areas would be represented in these susceptibility maps. In addition, it could be concluded that the calculated weights and the map produced based on Expert 2's opinion represented the best conformance with the actual landslide

database and its parametric distribution. It should be noted that the goal of these performance analyses is to check actual landslide conditions, not to analyze areas having no susceptibility to landsliding.

A predictive rate curve or confusion matrix evaluation could have been appropriate for the performance analyses, but in this case it would have been necessary to ask the experts for parametric relations of “no landslide conditions”. As it is not possible to express the parametric effects of these two conditions in the same matrix during the application of the AHP method, it was not taken into consideration in this study.

- (5) As emphasized previously, one of the crucial points of the present study was to compare the results with the work previously carried out by Ercanoglu (2005) in the same region using the ANN method. In other words, the comparison was between the “artificially trained brain” and the “expert opinion” provided from the selected experts.

According to Ercanoglu's (2005) landslide susceptibility map, 26.5% of the study area was classified as susceptible to landsliding, very close to the averaged total of the “very high” and “high” landslide susceptible areas (25.6%) in this study. Ercanoglu (2005) also indicated that 87.2% of the landslide areas were correctly classified by the ANN approach and the r_{ij} value was 0.85, considered a good performance. In the present study, generally higher values of r_{ij} were obtained for the landslide areas (Table 6).

With respect to the second performance approach (AHP), Ercanoglu's (2005) landslide susceptibility map represented an 8.8% better performance when the general average was considered. Although the ANN and the methodology employed in this study differ from each other fundamentally and mathematically, the results of the two methods could be considered as satisfactory and show a general agreement, particularly for the actual landslide areas. However, it should be noted that these assessments are only valid for the mapped landslides and the parameters considered in this study. In addition, when examined individually, there are some deviations from the general

Fig. 7 Landslide susceptibility maps based on ratings by **a** expert 1, **b** expert 2, **c** expert 3, **d** expert 4, **e** expert 5, **f** expert 6, **g** expert 7

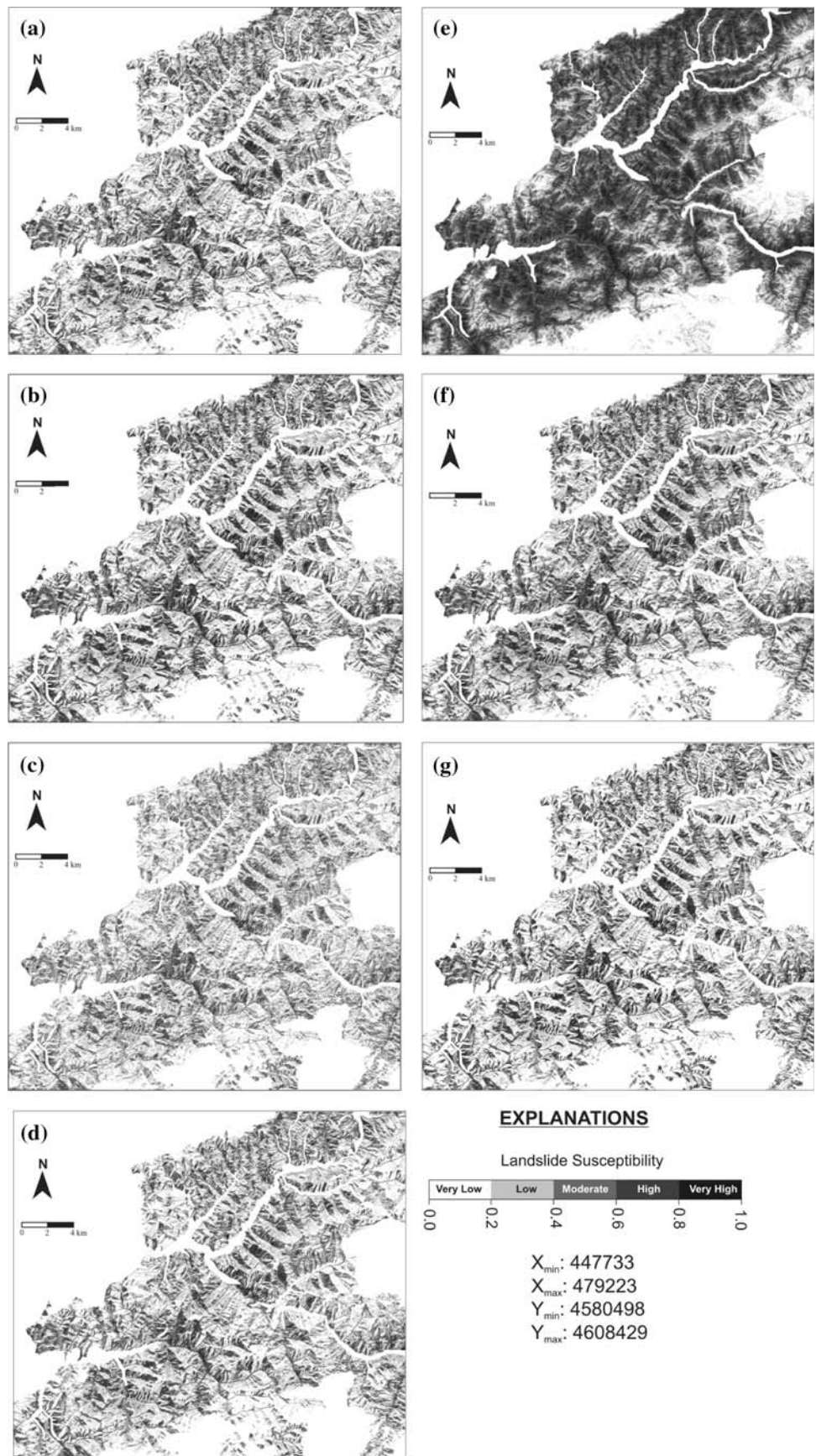


Table 5 Areal distribution of the landslide susceptibility levels in the study area

	Landslide susceptibility level (%)				
	Very low	Low	Moderate	High	Very high
Expert 1	20.8	34.3	22.6	16.3	6.0
Expert 2	20.4	34.2	20.1	17.7	7.6
Expert 3	24.1	33.9	24.7	13.3	4.0
Expert 4	22.9	35.0	21.6	15.4	5.1
Expert 5	6.7	15.0	29.1	34.8	14.4
Expert 6	17.3	32.1	25.3	17.6	7.7
Expert 7	26.9	33.3	14.2	17.3	8.3

Table 6 r_{ij} Values of the produced landslide susceptibility maps in the landslide areas

Landslide susceptibility map	r_{ij}
1	0.915
2	0.917
3	0.905
4	0.909
5	0.824
6	0.899
7	0.902
Average	0.896

Table 7 Areal distribution of the landslide susceptibility levels in the landslide areas

	Landslide susceptibility level (%)				
	Very low	Low	Moderate	High	Very high
Expert 1	3.5	5.2	6.9	21.5	62.9
Expert 2	3.7	5.7	6.4	11.0	73.2
Expert 3	4.8	5.2	7.5	27.3	55.2
Expert 4	4.6	5.7	6.7	32.5	50.5
Expert 5	3.6	7.9	24.4	47.3	16.8
Expert 6	3.5	5.6	7.2	30.1	53.6
Expert 7	4.4	6.3	10.9	22.7	55.7
Average	4.0	5.9	10.0	27.5	52.6

average, showing a better or worse performance. The real performance should be tested in terms of future landslides—whether or not they occur in the areas mapped as high or very high susceptibility zones.

- (6) Although the methodology employed in this study seems to be subjective, it provides useful information regarding the way landslide assessments are now being considered. It may have been interesting to use

some other parameters that might have been proposed by the experts, but this case, it was not possible to compare and test the results of the two methodologies (i.e. the ANN approach and the AHP) using the same database and parameters. Such an approach would be useful in the future.

- (7) Whatever methodology is employed, the importance—or necessity—of producing suitable maps is beyond question as they provide very useful information for urban development, land use planning etc. In addition, they constitute a basis for the landslide hazard and risk maps rarely used in countries such as Turkey. The pursuit of landslide assessment methods still needs to continue and geoscientists should progress this field of research.

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