Landslide susceptibility assessment: An application

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Introduction

Landslides, as one of the major natural hazards, account each year for huge property damage, in terms of both direct and indirect costs (Dai et al., 2002).

Landslides, defined as the movement of a mass of rock, debris or earth down a slope (Cruden, 1991), can be triggered by a variety of external factors, such as intense rainfall, earthquakes, water level change, rapid stream erosion (Bathrellos et al., 2009; Chousianitis et al., 2016; Dai et al., 2002; Rozos et al., 2011). Additionally, as development expands into unstable hill slope areas under the pressures of increasing population and urbanization, human activities such as deforestation or excavation of slopes for road cuts and building sites, etc., have become important triggers for landslide event (Bathrellos, 2005, 2014; Dai et al., 2002; Rozos et al., 2011).

Landslides have caused large numbers of casualties and huge economic losses in mountainous areas of the world. The most disastrous landslides have claimed as many as 100,000 lives (Li & Wang, 1992). In the USA, landslides cause an estimated US$ 1–2 billion in economic losses and about 25-50 fatalities annually, thus exceeding the average losses due to earthquakes (Schuster & Fleming, 1986). Li and Wang (1992) conservatively estimated that in China the number of deaths caused by landslides totaled more than 5,000 during the 1951-1989 period, resulting in an average of more than 125 deaths annually, and annual economic losses of about US$ 500 million.

Human losses and social-economic casualties due to landslides can be reduced through the effective planning and management. These approaches include:
(a) restriction of development in landslide-prone areas,
(b) use of excavation, classification, landscaping, and construction codes,
(c) use of physical measures (drainage, slope-geometry modification, and structures) to prevent or control landslides, and
(d) development of warning systems (Dai et al., 2002; Schuster, 1996; Schuster & Leighton, 1988; Slosson & Krohn, 1982).

Schuster and Leighton (1988) estimated that these methods could reduce landslide losses in California by more than 90%. Slosson and Krohn (1982) mentioned that establishment of these approaches had already reduced landslide losses in Los Angeles by 92-97%.

On the other hand, in spite of improvements in hazard recognition, prediction, mitigation measures, and warning systems, worldwide landslide activity is increasing (Dai et al., 2002). This trend is expected to continue in the 21st century for the following reasons (Schuster, 1996):
- increased urbanization and development in landslide-prone areas;
- continued deforestation of landslide-prone areas; and
- increased regional precipitation caused by changing climatic patterns.

In order to plan and manage effectively, a landslide hazard susceptibility has been preceded. The landslide-prone areas may be defined in advance.
Landslide susceptibility assessment

Landslides are among the most dangerous natural hazards worldwide, and in Hellas, affecting the development of an area. So, landslide susceptibility assessment is an important tool for the mitigation of this kind of disasters, but also a necessary step for land use and urban planning government policies worldwide (Carrara et al., 1991). Generally, the hazard assessment maps must be the useful and necessary tool for land use and urban planning government policies worldwide (Bathrellos et al., 2012, 2013, 2017; Kamberis et al., 2012; Papadopoulou-Vrynioti et al., 2013; Rozos et al., 2013; Youssef et al., 2015).

During the recent decades, a lot of work has been done to the direction of prediction and mitigation of landslide phenomena, such as the use of landslide susceptibility and hazard maps especially for land use planning. The aim of these maps is to classify the various parts of land surface according to the degree of actual or potential landslide hazard. Thus, the final receivers of these products, namely, the local authorities will be able to manage better the sites for urban or industrial planning and development.

The reliability of these maps depends mostly on the applied methodology as well as on the available data used for the hazard risk estimation (Parise, 2001). To this direction, GIS can help a lot with the spatial analysis of a landslide, i.e., a multi-dimensional phenomenon.

Numerous methods have been developed to assess the probability of landsliding. Soeters and van Westen (1996) and van Westen et al. (1997) divided these methods into inventory, heuristic, statistical, and deterministic approaches (Dai et al., 2002).

The semi-quantitative landslide assessment approaches (methods), like RES or AHP, can be considered as an effective expert’s tool for weighting and ranking the chosen parameters in an objectively optimal and simple way, which represent the main causes for landslide susceptibility of the study area.

The analytical hierarchy process (AHP) is a semi-quantitative, multi-objective and multi-criteria decision-making methodology (Saaty 1990, 2006), which has been widely applied for the solution of decision problems. This method comprises the analytical hierarchy of involved parameters and the comparison between the various pairs of them for the assignment of a relevant ratio for each parameter. In other words, it can estimate the weight of each parameter according to their preference, through the linear correlation of each one relative to the others. This is achieved by means of relevant correlation of them in pairs, as they are shown in a relative matrix, regarding the landslide vulnerability of the area. The ability of correlating different parameters, made this method a valuable tool for many researchers in compiling landslide susceptibility maps (Akgun & Bulut, 2007; Akgun et al., 2008; Ayalew et al., 2004, 2005; Castellanos Abella & van Westen, 2007; Komac, 2006; Rozos et al., 2011; Yalcin & Bulut, 2007). This method has been used in compiling and other hazards assessment maps (Bathrellos et al., 2012, 2013, 2016; Panagopoulos et al., 2012).
An application

In this study a method (AHP) is adopted in a GIS environment for the compilation of the corresponding landslide susceptibility maps.

The study area is part of Achaia County, which is located in the Northeastern part of Peloponnnesus and considered as one of the most mountainous regions of Greece, since 60% of its total area is highland (up to 2,341 m). The study area has an expanse of about 420 km² and its altitude varies from 0 to 1,760 m (Fig. 1). The landscape evolution of this area is controlled by the neotectonic action of the graben, which forms the Corinthian gulf. Therefore, the hydrographic network is well developed (Fig. 1), as it is controlled by fault tectonics in many cases, with its main axes to be orientated from SW to NE, namely the conjugate direction of the graben margin faults (Fig. 2).

![Fig. 1: The location map of the study area, with classes of elevation and hydrographic network.](image_url)

With regard to the climatic conditions of the study area (NE Peloponnnesus), the precipitation varies from 550-970 mm and because of its coastal extension the climate is classified as mild Mediterranean, without considerable temperature variations. The generally wet winter and dry summer are the defining characteristics of this climate.
Data and methodology

The following sources and data were used employing GIS, in preparing the landslide susceptibility map:

a. Topographic maps of Greek Military Service at a scale of 1:50,000,
b. The geological map of Greece at a scale of 1:50,000, Sheets Aigion and Dervenion of Institute of Geology and Mineral Exploration, IGME (1993, 2005).
c. The engineering geological maps of Achaia County at a scale of 1:50,000 and 1:100,000 (Rozos, 1989),
d. Precipitation records from eight stations, belonging to: (1) the Hellenic National Meteorological Service, (2) the Ministry for the Environment, Physical Planning and Public Works, (3) the Ministry of Agriculture and Ministry of Development. These records referred to mean annual precipitation for the period of 1975–2007.
e. The fieldwork of this study carried out during 2008–2009.

All the available data were utilized in the effort of the selection of the principal parameters and then for their GIS thematic layers. More analytically, the GIS software Arc-GIS v.9.3 was used for the creation of every data layer map. These maps were elaborated for the compilation of the final landslide susceptibility maps. At the beginning, all the relevant topographic, geological, tectonic and landslide manifestation maps were digitized. In the next step, the data from the topographic maps were used for the generation of the digital elevation model (DEM), with a cell size of 60 x 60 m, which was utilized in this study for the generation of the grid maps.
The parameters involved and their rating

The selection of the appropriate parameters has been based on:
(a) valuable knowledge from the work of other researchers, where similar methodologies have successfully been applied;
(b) the overall knowledge gained from the study of landslide phenomena in Greek territory;
(c) the experience gained through the systematic investigation and study of landslide activity in Achaia County and
(d) the extended field observations in the frame of this study.

The parameters, which were finally selected for the applied methodology, were the following ten:
(1) lithology,
(2) distance from tectonic lineaments,
(3) slope angle,
(4) slope aspect,
(5) rainfall,
(6) altitude,
(7) land use,
(8) distance from roads,
(9) distance from rivers, and
(10) geometry of main discontinuities.

The study area was subdivided into two parts, following the boundaries of the two topographic maps involved. The western part, called Aigion area, was chosen to be the ranking site, where the characteristics of the slope movements, the experience of the study team, and the suggestions of previous works helped for the selection of the principal parameters. The weighting coefficients of these parameters were selected and applied in the method. The eastern part, called Dervenion area, was the application site. This site was used for the application of AHP method, and its final landslide susceptibility map was compiled.

A number of 277 sites of landslide manifestation were examined throughout the study area. These sites were used for establishing the principal parameters, their ratings and their weighting coefficients for this method.

Each parameter was then separated into 5 classes, with a rating from 0 to 4. Every class represents specific conditions, as they have been investigated and recorded in the study ranking area. Thus, the class, which was rated as 0, represented the most stable conditions (minor landslide risk) and the one rated as 4 the most favorable conditions for slope failure (major landslide risk).

In Table 1 the selected principal parameters, their classes and their ratings are shown, alongside the relative density of the landslides. The density of landslides is the ratio between the areas covered by the pixels of landslides, which represent a class of a
parameter and the total landslide area. This density, expressed in percentages, was thought to be the basic factor for the rating of every class of the principal parameters.

Table 1: Classes and ratings of adopted principal parameters, with landslide density (%) distribution for each class (Rozos et al., 2011).

<table>
<thead>
<tr>
<th>Description</th>
<th>Landslide density (%)</th>
<th>Rating</th>
<th>Description</th>
<th>Landslide density (%)</th>
<th>Rating</th>
<th>Description</th>
<th>Landslide density (%)</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lithology</td>
<td></td>
<td></td>
<td>2. Distance from Tectonic lineaments</td>
<td></td>
<td></td>
<td>3. Slope angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately to thick-bedded limestones</td>
<td>2.36</td>
<td>0</td>
<td>Distant (&gt;200 m)</td>
<td>11.13</td>
<td>0</td>
<td>0°-5°</td>
<td>13.63</td>
<td>0</td>
</tr>
<tr>
<td>Thin bedded schist chert formations</td>
<td>3.15</td>
<td>1</td>
<td>Moderate distant (151-200 m)</td>
<td>8.30</td>
<td>1</td>
<td>5°-15°</td>
<td>20.63</td>
<td>1</td>
</tr>
<tr>
<td>Plio-Pleistocene coarse-grained sediments</td>
<td>16.05</td>
<td>2</td>
<td>Near (101-150 m)</td>
<td>14.18</td>
<td>2</td>
<td>15°-30°</td>
<td>42.10</td>
<td>2</td>
</tr>
<tr>
<td>Quaternary formations fine, fine-coarse to coarse, and loose to semi-coherent</td>
<td>20.32</td>
<td>3</td>
<td>Very near (51-100 m)</td>
<td>27.78</td>
<td>3</td>
<td>31°-45°</td>
<td>17.97</td>
<td>3</td>
</tr>
<tr>
<td>Plio-Pleistocene fine-grained sediments and Flysch formations</td>
<td>54.52</td>
<td>4</td>
<td>Nearest (0-50 m)</td>
<td>38.60</td>
<td>4</td>
<td>&gt;45°</td>
<td>5.67</td>
<td>4</td>
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<tr>
<td>181°-225°</td>
<td>9.89</td>
<td>0</td>
<td>&lt;60 mm</td>
<td>0.00</td>
<td>0</td>
<td>&gt;1200 m</td>
<td>0.00</td>
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<tr>
<td>136°-180°</td>
<td>10.01</td>
<td>1</td>
<td>650-700 mm</td>
<td>2.90</td>
<td>1</td>
<td>801-1200 m</td>
<td>5.57</td>
<td>1</td>
</tr>
<tr>
<td>91°-135°, 235°-270°</td>
<td>23.52</td>
<td>2</td>
<td>701-750 mm</td>
<td>14.29</td>
<td>2</td>
<td>501-600 m</td>
<td>20.27</td>
<td>2</td>
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<tr>
<td>46°-90°, 371°-315°</td>
<td>25.69</td>
<td>3</td>
<td>751-800 mm</td>
<td>27.98</td>
<td>3</td>
<td>&lt;250 m</td>
<td>29.15</td>
<td>3</td>
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<tr>
<td>0°-45°, 316°-360°</td>
<td>30.88</td>
<td>4</td>
<td>&gt;800 mm</td>
<td>54.83</td>
<td>4</td>
<td>250-500 m</td>
<td>45.01</td>
<td>4</td>
</tr>
<tr>
<td>7. Land use</td>
<td></td>
<td></td>
<td>8. Distance from roads</td>
<td></td>
<td></td>
<td>9. Distance from rivers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barren areas</td>
<td>1.20</td>
<td>0</td>
<td>Distant (&gt;200 m)</td>
<td>17.01</td>
<td>0</td>
<td>Distant (&gt;200 m)</td>
<td>18.54</td>
<td>0</td>
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<tr>
<td>Urban areas</td>
<td>4.44</td>
<td>1</td>
<td>Moderate distant (151-200 m)</td>
<td>8.09</td>
<td>1</td>
<td>Moderate distant (151-200 m)</td>
<td>12.13</td>
<td>1</td>
</tr>
<tr>
<td>Forest areas</td>
<td>13.70</td>
<td>2</td>
<td>Near (101-150 m)</td>
<td>14.50</td>
<td>2</td>
<td>Near (101-150 m)</td>
<td>14.08</td>
<td>2</td>
</tr>
<tr>
<td>Shabby areas – Natural grasslands</td>
<td>37.95</td>
<td>3</td>
<td>Very near (51-100 m)</td>
<td>24.42</td>
<td>3</td>
<td>Very near (51-100 m)</td>
<td>22.85</td>
<td>3</td>
</tr>
<tr>
<td>Cultivated areas</td>
<td>42.71</td>
<td>4</td>
<td>Nearest (0-50 m)</td>
<td>35.98</td>
<td>4</td>
<td>Nearest (0-50 m)</td>
<td>32.4</td>
<td>4</td>
</tr>
<tr>
<td>Drive against</td>
<td>22.07</td>
<td>0</td>
<td>Drive against</td>
<td>22.07</td>
<td>1</td>
<td>Drive sideways and vertical</td>
<td>10.9</td>
<td>2</td>
</tr>
<tr>
<td>Drive with, having a dip of &gt;50°</td>
<td>18.34</td>
<td>3</td>
<td>Drive with, having a dip of 1-15°</td>
<td>18.34</td>
<td>3</td>
<td>Drive with, having a dip 16-30°</td>
<td>23.9</td>
<td>4</td>
</tr>
</tbody>
</table>

Lithology

Lithology is one of the most decisive parameters regarding the landslide manifestation. For the study area the classes of lithology have arisen from its geological setting, based on literature (IGME 1993, 2005; Rozos 1989) and fieldwork. The distinctive geological formations were digitized and unified according to their engineering geological behaviour, in relation to landslide manifestation. Thus, lithology includes five classes as follows: (a) moderate to thick-bedded limestones, (b) thin bedded schist chert formations, (c) Plio-Pleistocene coarse-grained sediments, (d) fine, fine-coarse to coarse and loose to semi-coherent Quaternary formations, (e) Cyclothematic formations (Plio-Pleistocene fine-grained sediments and Flysch
Regarding the density of landslides, the higher percentage is attributed to Cyclothematic formations (Plio-Pleistocene fine-grained sediments and Flysch formations) and thus this class has the higher rate (4) (Fig. 3).

Distance from tectonic lineaments

The active tectonics in the study area plays an important role in the landslide manifestation. The various tectonic lineaments were collected from literature (IGME 1993, 2005; Rozos 1989) and fieldwork. All tectonic lineaments (faults, overthrusts, etc.) were digitized and buffer zones were formulated around them at distances of 50, 100, 150 and 200 m. Thus, the classes of the buffer zones are five, namely: (1) the nearest (0-50 m), (2) the very near (51-100 m), (3) the near (101-150 m), (4) the moderate distant (151-200 m) and (5) the distant (>200 m). As it was expected the lower the landslide density values the higher the distance from the relevant tectonic lineaments. Thus, the most prone class to landslide is that of 0-50 m, taking the highest rate (4) (Fig. 4).

**Fig. 3:** The thematic layer of Lithology
Slope angle

The angle and the aspect of the slopes play a very important role in the manifestation of the landslides because they express the result of the combined influence of many agents. Contours with 20 m intervals were digitized from topographic sheets and saved as line layer. A digital elevation model (DEM) was derived from the digitized elevation data using 3D analyst extension of ArcGIS, and the slope layer was extracted from it. The grid maps of the slope angle with cell size 60 x 60 m were classified into five classes, as follows: (1) 0°-5°, (2) 6°-15°, (3) 16°-30°, (4) 31°-45°, and (5) >45°, with the higher rating to be given to the slopes with the higher inclination, despite the higher landslide density is in the classes 6°-15° and 16°-30°. This peculiar condition can be explained easily as in nature, slopes consisting of soil or hard soil to soft rocky formations (like those of the study area), and having high angle, fail almost immediately after their formation giving lower slope angles. Finally, the slopes with an inclination of around the angle of friction are those, which fail after the action of triggering factors. On the other hand, rocky slopes are stable even in high angles suffering only from rock falls, wedge failures, etc (Fig. 5).

Fig. 4: The thematic layer of distance from tectonic lineaments.
Slope aspect

For the classification of the slope aspect, the grid maps of this parameter were produced with cell size 60 x 60 m elaborating the DEM. These maps were classified into five classes, including in some cases more than one range of aspects, namely: (1) SW 181°-225°, (2) SE 136°-180°, (3) ESE 91°-135° and SWW 226°-270°, (4) NEE 46°-90° and WNW 271°-315°, (5) NNE 0°-45° and NWN 316°-360°.

As it was revealed from the fieldwork, most of the landslides are manifested in the slopes with orientation from northwest to northeast. So these orientations constitute the classes with the higher rating 3 and 4 (Table 1, Fig. 6).
Rainfall

As it is well known, precipitation is among the most usual triggering factors for landslide manifestation. The stations used are well distributed in the study area both hypsometrically and territorially, giving very good results regarding the distribution of the precipitation. The mean annual precipitation of the area is between 550.7 and 973.1 mm. For the necessities of this study, the precipitation map was produced, using the data of the main meteorological stations in the area and applying the Inverse distance weighted (IDW) interpolation method. This map was separated into 5 classes, i.e.: (1) <650 mm, (2) 651-700 mm, (3) 701-750 mm, (4) 751-800 mm, and (5) >800 mm. Landslide density percentage is higher as the precipitation increases and thus the higher the precipitation, the higher the rating (Table 1, Fig. 7).
Altitude
The altitude does not contribute directly to landslide manifestation, but in relation to the other parameters, like tectonics, erosion–weathering processes, and precipitation, the altitude contributes to landslide manifestation and influences the whole system. The grid maps of the altitude with cell size 60 x 60 m were produced from the DEM. The separation of the altitude into 5 classes, i.e. (1) <250 m a.s.l., (2) 250-500 m a.s.l., (3) 501-800 m a.s.l., (4) 801-1,200 m a.s.l., and (5) >1,200 m a.s.l., was based on the morphology of the study area in relation to the landslide occurrence. The increasing of the altitude is not in a direct relation to the landslide density, with the higher density percentage to attributing to second class (250–500 m a.s.l.). This is because Plio-Pleistocene sediments with the maximum percentage of landslide density mainly occupy the hilly to semi-hilly morphological relief (Table 1, Fig. 8).
Land use

The data for the land use were taken from CORINE program (Bossard et al., 2000) and were saved as polygon layer. The variation of the vegetation in an area is a parameter that seriously affects the slope failures, as slope stability is very sensitive in changes on vegetation. For the necessities of this study, the land use, which reflects the vegetation covering, was classified into 5 categories as follows: (1) barren areas, (2) urban areas, (3) forest areas, (4) shrubby areas–natural grasslands, and (5) cultivated areas. The maximum percentage of landslide density is attributed to cultivated areas with the higher rating (Table 1, Fig. 9).

Fig. 8: The thematic layer of altitude.
**Distance from roads**

As it is obvious, the artificial and natural parts of the slopes around a road are more sensitive in landslide manifestation. Therefore, the road network was chosen as a principal parameter and was digitized and saved as line layers in the GIS database, using the topographic sheets as data source. Buffer zones were created around the roads of the area at distances of 50, 100, 150 and 200 m. Thus, the classes of the buffer zones are five, namely: (1) the nearest (0-50 m), (2) the very near (51-100 m), (3) the near (101-150 m), (4) the moderate distant (151-200 m) and (5) the distant (200 m). The highest percentage of landslide density refers to the “nearest” class with the high rating (Table 1, Fig. 10).
Distance from rivers

Similar to the road network, the hydrographic network was digitized and saved as line layers in the GIS database, using the topographic sheets as data source. The hydrographic axes continuously change the slopes of the rivers and can therefore be considered as one of the principal parameters in landslide manifestation. For the examination of this parameter, buffer zones were created around the bed of the rivers and the streams of the area, at distances of 50, 100, 150 and 200 m. These distances start counting from the river’s bed boundaries from both sides. This is because the beds of the rivers are usually flat places where no landslide occurs. Finally, the classes of the buffer zones are also five, like for roads: (1) the nearest (0-50 m), (2) the very near (51-100 m), (3) the near (101-150 m), (4) the moderate distant (151-200 m) and (5) the distant (>200 m). The percentage of landslide density reduces as the distance from the hydrographic axes increases, thus, the highest percentage of landslide density refers to the nearest class (Table 1, Fig. 11).

It is noticeable that in roads and rivers, but also in tectonic lineaments a significant percentage of landslide density is ascribed to distances >200 m. This is not peculiar, as other parameters affect the area >200 m and influence the landslide manifestation.

Fig. 10: The thematic layer of distance from roads.
Geometry of main discontinuities

The geometry of the main discontinuities in relation to slope geometry (aspect) is strongly related to the stability of hard soils, and soft rocks. Thus, the map of the main discontinuities was compiled using the relevant literature (Rozos 1989; IGME 1993, 2005) and the observations during the fieldwork. The recorded dips and dip directions of the formations were digitized and saved as a map of GIS database. The formations without dip were characterized as “no data formations”. In a next step, the map was converted in raster format and combined to the slope aspect map. Therefore, the correlation of the dip direction of strata with the slope aspect was able to be done and the classes “drive against”, “drive sideways and vertical” as well as “drive with” were formulated, with the highest percentage of landslide density to be attributed to the “drive with” class. With regard the “drive with” class, its combination with the friction angle of the Cyclothemetic formations (Neogene and flysch) gave space in another three classes namely “drive with having a dip of 1°-15°”, “drive with having a dip 16°-30°” and “drive with having a dip of >30°”. Thus, the overall classes were 5, as follows: (1) drive against, (2) drive sideways and vertical, (3) drive with, having a dip of 1°-15°, (4) drive with, having a dip 16°-30°, (5) drive with, having a dip of >30° (Fig. 12).

Fig. 11: The thematic layer of distance from rivers.
AHP method

The AHP method is well known and widely used for the solution of multi-parametric problems, as the factors for the landslide susceptibility maps can be evaluated by it. The application of this method implements a linear correlation of the parameters involved, while their weighting coefficients are revealed via pair-wise comparison from a table-matrix with the relevant values. The pair-wise comparison process is performed using a nine point scale, the numerical values of which and the corresponding levels of importance are: 1 = equal, 3 = moderately, 5 = strongly, 7 = very strongly, 9 = extremely 2,4,6,8 = intermediate values (Saaty 1977).

During the construction of the table-matrix every principal parameter is rated in relation to any other with a value from 1/9 to 9. These numerical values represent the relevant significance of a parameter to the others regarding its applicability for the purpose of the study.

When the comparison is applied vice versa, the adopted numerical value is the reciprocal of the first one. In a next step, all the numerical values are normalized by dividing each entry of every column by the sum of all the entries in that column, so that they sum up to 1. Following the subsequent normalization, the values were

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Fig. 12: The thematic layer of geometry of the main discontinuities.
averaged across the rows to give the relative importance weight for each factor (Saaty 2006).

The calculation of the weighting coefficient of every adopted principal parameter in this study for AHP method is given in Table 2. After the creation of the table-matrix and the correlation of the principal parameters, its implication was checked with consistency ratio (CR). This ratio is used in order to avoid the creation of any incidental judgment in the matrix. When the consistency ratio is less than 0.1, the calculated weighting coefficients are acceptable. On the contrary, if that ratio is greater than 0.1, then, a reassessment of the judgments is demanded in the table-matrix. The CR from the application of the AHP in this study is 0.05 (Table 2).

Thus, the judgments depicted in Table 2 are well assessed. All the pair comparisons, the eigenvectors, the weights and the consistency ratio were calculated using the Expert Choice 11 software.

Finally, as it can be seen from Table 2 the parameter with the highest weighting coefficient is the inclination of the slopes, followed by the rainfall, the geometry of main discontinuities and the lithology.

Table 2: The principal parameters and the calculation of their weighting coefficient for the AHP method (Rozos et al., 2011).

<table>
<thead>
<tr>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
<th>P8</th>
<th>P9</th>
<th>P10</th>
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<td>2</td>
<td>1/3</td>
<td>3</td>
<td>1/2</td>
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<td>1/6</td>
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P1 = Lithology, P2 = Distance from tectonic, P3 = Slope, P4 = Aspect, P5 = Rainfall, P6 = Altitude, P7 = Land use, P8 = Distance from roads, P9 = Distance from rivers, P10 = Geometry of main discontinuities.
Landslide susceptibility map

After the application of the AHP, a linear correlation between the weighting coefficients of the method and the raster layers of the principal parameters involved was established, aiming to the total estimation of the ratings. Thus, the compilation of the final landslide susceptibility map was feasible. This linear correlation is given by the formula:

\[ O = \sum_{i=1}^{n} P_i W_i \]

Where, \( O \) = the overall score, \( n \) = the number of the parameters, \( P_i \) = the parameter i, \( W_i \) = the weighting coefficient of the parameter i.

After the interaction of the examined principal parameters for AHP method and the calculation of its weighting coefficients, these coefficients were linearly correlated with the relevant thematic levels. This procedure helps in the compilation of the final susceptibility map.

Fig. 13: The landslide susceptibility map from the AHP method.
The classification at present was carried out using standard deviation and the examined area was separated into five categories of landslide susceptibility, as follows: (1) very low, (2) low, (3) moderate, (4) high and (5) very high. The compiled susceptibility map from AHP is given in the Fig. 13.

Regarding the spatial development of the landslide susceptibility zones, their percentages to the total area from AHP map are: 6.97% for the ‘‘very low’’ zone, 23.60% for the ‘‘low’’ zone, 38.16% for the ‘‘moderate zone, 24.75% for the ‘‘high’’ zone, 6.52% for the ‘‘very high’’ zone.
Exercise: Landslide susceptibility assessment

Landslides are a part of the geomorphological cycle forming the Earth’s surface. Landslides are hazardous when they affect human activities or vice versa when human activities cause these phenomena.

The manifestation of a landslide is a result of combined action of many factors. These parameters can be related to geological structure, lithology of rocks, tectonic activity, erosion, stress distribution, morphology, climatic conditions and the human activities. The action of these parameters produces a drastic increase of instability of the earth's surface masses, causing landslide (Bathrellos et al., 2009).

The main aim of landslide susceptibility assessment is to reduce the impact of the landslide even. The landslide susceptibility assessment results the production of thematic maps with graded levels of susceptibility (Fig. 14)

![Landslide Susceptibility Map](image)

**Fig. 14:** The landslide susceptibility map in Trikala Prefecture, Western Thessaly – Central Greece (source: Bathrellos 2005).

Objectives-Methods

The action of several factors affects the appearance of a landslide manifestation. Such as factors are: lithology of bedrock, slopes, road network, land use etc. The study and evaluation of these factors provides important outcomes about the landslide susceptibility of a given area.

Problems

1. Landslide occurrence of landslides is a regular phenomenon, especially in the mountainous area of Pindos Range, Central Greece. They can cause serious damage at sections of urban areas and at the road network (Bathrellos, 2014). Figure 15 shows the road network, the drainage basin and the lithological formations which appears in
the area of settlements Ropoto and Vatsounia. The study area is located in south Pindos Range, Central Greece. Identify which areas of the map of figure 15 are susceptible for landslide occurrences? Why?

![Fig. 15: The lithological formations which appears in the area of settlements Ropoto and Vatsounia, Central Greece. The road network and the drainage network are also illustrated.](image)

2. The slopes of the study area were classified into five classes: (i) <5°, (ii) 5°-15°, (iii) 15°-30°, (iv) 30°-45°, and (v) >45°. The spatial distribution of the slopes is shown in figure 16. Which areas of the map are susceptible for landslide events? Why?

![Fig. 16: The morphological slopes in the area of settlements Ropoto and Vatsounia, Central Greece.](image)
3. The land uses of the study area were classified into four categories: (i) densely urban areas, (ii) cultivated areas, (iii) shrubby area, and (iv) forests (Fig. 17). Which areas of the map are susceptible for landslide events? Why?

![Fig. 17: The land uses in the area of settlements Ropoto and Vatsounia, Central Greece.](image)

4. The landslides prone regions of the study area may be identified using the information of the previous questions (1 - 3). Divide spatially the study area in three categories of susceptibility level: high, medium and low. Outline the three categories on the map of figure 18.

![Fig. 18: The landslide susceptibility map for the area of settlements Ropoto and Vatsounia, Central Greece.](image)
References


