LANDSLIDE SUSCEPTIBILITY ASSESSMENT: An application

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Landslides

- Landslides are a part of the *geomorphological cycle* during the formulation of earth's surface.
- Landslides, defined as the *movement* of a mass of rock, debris or earth down a slope.
- The landslide events are hazardous when:
  - affect *human activities* or/and
  - *human activities* causing these *phenomena*.
- Landslides have caused large numbers of casualties and huge economic losses in mountainous areas of the world.
- Worldwide, *annual economic losses* from landslides is estimated to US $ 5 billion.
• Landslides occur with greater frequency in relation to our ability to restore the effects of past events.

• In spite of improvements in hazard recognition, prediction, mitigation measures, and warning systems, worldwide landslide activity is increasing. This trend is expected to continue in the 21st century for the following reasons:
  • 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 susceptibility assessment has been preceded. The landslide-prone areas may be defined in advance.
• What **causes landslide events?**
• Which is the **factor?**

• **One factor**

or **COMPINATION of many factors?**
• Why? Why in one area and not elsewhere;
Landslide susceptibility assessment

- **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.

- Prediction and mitigation of landslide phenomena: the use of landslide susceptibility maps.

- These maps **classify** the various parts of land surface according to the **degree** of **actual** or **potential landslide hazard**.

- 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.

- **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:

- into inventory,
- heuristic,
- statistical, and
- deterministic approaches

The *semi-quantitative* landslide assessment approaches (methods), like Analytical Hierarchy Process (AHP), can be considered as an effective expert’s tool for weighting and ranking the chosen parameters, which represent the main causes for landslide susceptibility of the study area.
• The **AHP** is a semi-quantitative, multi-objective and multi-criteria decision-making methodology.

• 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.

• 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, it a **valuable tool** for many researchers in **compiling landslide susceptibility maps**
An application

The study area is part of Achaia County, which is located in the Northeastern part of Peloponnnesus.

The location map of the study area, with classes of elevation and hydrographic network.

The simplified geological map of the study area
The following data were used:

- Topographic maps of Greek Military Service at a scale of 1:50,000,
- 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).
- The engineering geological maps of Achaia County at a scale of 1:50,000 and 1:100,000
- Precipitation records from eight stations. These records referred to mean annual precipitation for the period of 1975–2007.
- Fieldwork.
Methodology

The study area was subdivided into two parts, following the boundaries of the two topographic maps involved.

- The **western part**: the ranking site, where the characteristics of the slope movements helped for the selection of the principal parameters.

- The **eastern part**: was the application site, was used for the application of AHP method, and its final landslide susceptibility map was compiled.
The parameters involved

The parameters, which were finally selected for the applied methodology, were the following ten:

- lithology,
- distance from tectonic lineaments,
- slope angle,
- slope aspect,
- rainfall,
- altitude,
- land use,
- distance from roads,
- distance from rivers, and
- geometry of main discontinuities.
Lithology is one of the most decisive parameters regarding the landslide manifestation.
Distance from tectonic lineaments

The active tectonics in the study area plays an important role in the landslide manifestation.

All tectonic lineaments (faults, overthrusts, etc.) were digitized and buffer zones were formulated around them at distances of 50, 100, 150 and 200 m.
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.
Slope aspect
Rainfall

Precipitation is among the most usual triggering factors for landslide manifestation.
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.
Land use

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.
Distance from roads

The artificial and natural parts of the slopes around a road are more sensitive in landslide manifestation. Buffer zones were created around the roads of the area at distances of 50, 100, 150 and 200 m.
Distance from rivers

The hydrographic axes continuously change the slopes of the rivers and can therefore be considered as one of the principal parameters in landslide manifestation. Buffer zones were created around the bed of the streams of the area, at distances of 50, 100, 150 and 200 m.
The geometry of the main discontinuities in relation to slope geometry (aspect) is strongly related to the stability of hard soils, and soft rocks. The recorded dips and dip directions of the formations combined to the slope aspect map.
Rating of adopted principal parameters

An number of 277 sites of landslide manifestation were examined throughout the study area.

The density of landslides was the basic factor for the rating of every class of the principal parameters.

Each parameter was then separated into five classes, with a rating from 0 to 4.

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).
<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>
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</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>
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<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>6°-15°</td>
<td>20.63</td>
<td>1</td>
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<tr>
<td>Plio-Pleistocene coarse-grained sediments</td>
<td>16.65</td>
<td>2</td>
<td>Near (101-150 m)</td>
<td>14.18</td>
<td>2</td>
<td>16°-30°</td>
<td>42.10</td>
<td>2</td>
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<tr>
<td>Quaternary formations fine, fine - coarse to coarse,</td>
<td>23.32</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>
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<tr>
<td>and loose to semi-coherent</td>
<td></td>
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<tr>
<td>Plio-Pleistocene fine-grained sediments and Hysch</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>
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<tr>
<td>181°-225°</td>
<td>9.89</td>
<td>0</td>
<td>&lt;650 mm</td>
<td>0.00</td>
<td>0</td>
<td>&gt;1200 m</td>
<td>5.57</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>20.27</td>
<td>2</td>
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<tr>
<td>91°-135°, 226°-270°</td>
<td>23.52</td>
<td>2</td>
<td>701-750 mm</td>
<td>14.29</td>
<td>2</td>
<td>501-800 m</td>
<td>29.15</td>
<td>3</td>
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<tr>
<td>46°-90°, 271°-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>45.01</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>
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<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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<td>Urban areas</td>
<td>4.44</td>
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<td>8.09</td>
<td>1</td>
<td>Moderate distant (151-200 m)</td>
<td>12.13</td>
<td>1</td>
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<td>Forest areas</td>
<td>13.70</td>
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<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>
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<tr>
<td>Shrubby 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>10. Geometry of main discontinuities</td>
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<td></td>
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<tr>
<td>Drive against</td>
<td>23.07</td>
<td>0</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Drive sideways and vertical</td>
<td>23.79</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Drive with, having a dip of &gt;30°</td>
<td>10.9</td>
<td>2</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Drive with, having a dip of 1-15</td>
<td>18.34</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive with, having a dip 16-30°</td>
<td>23.9</td>
<td>4</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
AHP method

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.

The **table-matrix** every principal parameter is rated in relation to any other with a value from 1/9 to 9. These values represent the relevant significance of a parameter to the others.

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 **one**.

The table-matrix was checked with **consistency ratio (CR)**. When the consistency ratio is **less than 0.1**, the calculated weighting coefficients are **acceptable**.
All the pair comparisons, the eigenvectors, the weights and the consistency ratio were calculated using the *Expert Choice*.
Overall estimation

The linear correlation between the weighting coefficients of the method and the raster layers of the principal parameters is given by the formula:

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

Where:

- \( O \) = the overall score of landslide susceptibility index
- \( n \) = the number of the parameters,
- \( P_i \) = the parameter \( i \),
- \( W_i \) = the weighting coefficient of the parameter \( i \).
Results - Landslide susceptibility map

Legend
- Main settlements
- Landslide susceptible zone
  - Very low
  - Low
  - Moderate
  - High
  - Very high

Corinthian Gulf

Monastirion

Kelkha

Pyros

Ellinikon

Lykoria

Lygia

Derbenion

Algeira

Akrata

Platanos

Belini

Alqar

Kallithea

0 1 2 4 Km

22°18'0"E
22°28'30"E

38°3'30"N
<table>
<thead>
<tr>
<th>Landslide susceptibility zones</th>
<th>Percentages to the total area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>6.97</td>
</tr>
<tr>
<td>Low</td>
<td>23.60</td>
</tr>
<tr>
<td>Moderate</td>
<td>38.16</td>
</tr>
<tr>
<td>High</td>
<td>24.75</td>
</tr>
<tr>
<td>Very high</td>
<td>6.52</td>
</tr>
<tr>
<td><strong>Σύνολο</strong></td>
<td>100.00</td>
</tr>
</tbody>
</table>
REFERENCES


