

The Impact of Earthquake Induced Landslides on the Terrain Predicted by Means of Landslides Susceptibility Maps. The Case of the Lefkada Island.

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Abstract

The occurrence of landslides is frequent in Greece. The current study focuses on Lefkada Island presenting the highest landslide occurrence among the Ionian Sea islands, on the west coast of Greece.

The Ionian Islands have suffered from many destructive earthquakes and Lefkada holds a key position among them. The main failure mechanism occurring is rock fall. The most common preparatory factors of these events are the steep morphology and the type of the geological formations, while their triggering event is the seismic activity.

Although landslides cannot be predicted accurately, many attempts have been made to compile susceptibility maps on a global or continental scale. Mapping areas susceptible to landslides is essential for the strategic planning and management of the land-use.

In the present study, diverse data such as geological formations, tectonic structures, pre- and post- earthquake landslides, geomorphologic and topographic features were compiled for the preparation of the susceptibility map. The above data was digitized and imported in a Geographic Information System (GIS). Afterwards, thematic layers of lithology, slope angle, slope aspect, tectonic lineaments, drainage network and road network were developed. After the creation of the these layers, GIS techniques were applied, in order to produce the maps by means of the weighted linear combination - W.L.C., semi quantitative method.

Keywords: Landslides Susceptibility Maps, Lefkada Island, WLC, Geohazards

Introduction

Geohazards are geological and environmental conditions, which involve long-term or short-term geological processes. Landslides, as a major type of geological hazard, represent one of the natural events that occur most frequently worldwide after hydro-meteorological events. Landslides occur when the stability of a slope changes due to a number of factors. For example the steep terrain, prolonged precipitation, active tectonic and seismicity are some of the factors making a region prone to landslides.

Identification of landslides and compilation of landslide susceptibility maps are very important issues for the engineering geologists and for the public authorities. A landslide susceptibility map depicts areas likely to have landslides in the future by correlating some of the principal factors that contribute to landslides with the past distribution of slope failures. Although landslides cannot be predicted accurately, many attempts have been made to compile susceptibility maps on a global or continental scale. The type and level of detail of

the zoning and the scale of the maps depends on the purpose to which the landslide zoning is to be applied. Important factors for the compilation of reliable maps are the quality and the amount of available data and the selection of the best method for the analysis.

Many methods have been developed and applied for the preparation of landslide susceptibility maps, risk and hazard. The applied methods are divided into three main categories quality, based on the experience of specific, semi-quantitative and quantitative, based on formulas (Lee and Jones 2004; Castellanos Abella and van Westen 2008).

In this study, the qualitative susceptibility analysis using relative weighting-rating system has been adopted for landslide susceptibility zonation. The goal of the present study is the implementation of the WLC method in an area which suffers from severe landslide phenomena, situated within the geographic limits in Lefkada Island (fig.1).



Figure. 1: Location map of the area, Lefkada Island, Greece

Study Area

The island of Lefkada is located in Western Greece and it is one of the seven islands in Ionian Sea, connected to the mainland by a long causeway and floating bridge.

The geology of the island comprises alpine, molassic and post alpine formations. The Alpine formations include the Paxos Zone formations and the overthrust formations of the Ionian Zone (fig.2).

The Paxos Zone formations are located on the southwestern part of Lefkada Island and are composed of a continuous sequence of Late Jurassic to Oligocene carbonate rocks grading towards the upper members to a Miocene sequence of siliceous limestone. The Ionian Zone formations dominate the island and are composed of a series of Late Triassic (Bathrellos et al, 2009).

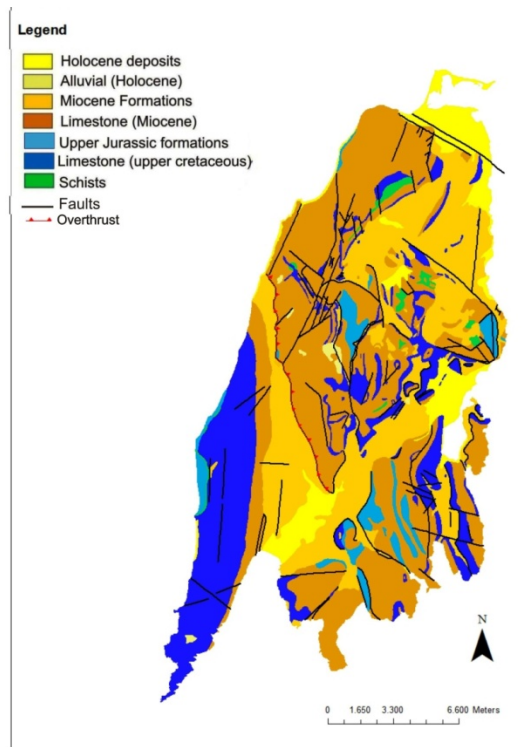


Figure 2: Simplified geological map of Lefkada Island

The Ionian Islands have suffered from many destructive earthquakes. The island of Lefkada in the central Ionian Sea presents high seismicity, holding a key position in western Greece, where the Hellenic subduction, in the south, passes to the Adriatic collision, in the North, through the right-lateral Kefalonia fault (also called Kefalonia - Lefkada Transform fault – KLTF) (Rondoyanni et al, 2012). Due to the large earthquake in 2003 numerous landslides have occurred. The main failure mechanism occurring is rock fall. The most important preparatory factors of these events are the steep morphology and the type of the geological formations, and they were triggered by the seismic activity (fig.3).



Figure 3: a) Rockfalls in the provincial network for Agios Nikitas (the longest landslide in Lefkada), b) Flat slides on the rocky slope to the road network near Kalamitsi, c) Landslide near Nikolis village, d) Rockfalls in the provincial network for Agios Petros in Lefkada island

Methodology

Mapping areas susceptible to landslides is essential for the strategic planning and management of the land-use.

The data used for the composition of maps is:

- Topographic maps of the Military Geographical Service, scale 1:50,000
- Geologic map of IGME, scale 1:50,000 (Sheet Lefkada)
- Digital Terrain Model (DEM) (cell size 5x5), provided by the Ktimatologio SA
- File Exploration and studies by the Institute of Geology and Mineral Exploration as well as by the Universities (PhD thesis etc.) and the national Institutes regarding the landslides of Lefkada.
- Field data involving observations on geology, tectonic structures, and pre- and post- earthquake landslides.

To store, unify correct and process the complex information described above GIS technology was chosen as the best solution for the input, storage, management, analysis and cartographic representation of such geographic information. The software used for the development of the specific GIS application is ArcGIS 9x,.

Preparation of Thematic Maps

For the landslide susceptibility map construction, according to the method WLC, individual thematic maps drafted for spatially distributed parameters which found to have an impact in the event of landslides. The parameters taken into account are the geology, the existence of faults, the roads, the river network, morphological gradients, address morphological gradients, rainfall, land use, etc.

In each of the thematic maps the spatially distributed data is divided into classes depending on their characteristics, for example the type of geological formation, the distance from faults etc. Each class carries a degree (rating, R) depending on the degree of influence in the event of landslides, which ranges from 1 to 10. In order to produce the final map landslide susceptibility maps summed individual, after multiplication with a degree of gravity (weight, W) which expresses the degree of influence of the parameter, as a whole, in the event of landslides. The individual weights of parameters and degrees of partial fractions were selected for this study is presented in Table 1.

In the standard method WLC simple landslide susceptibility index (LSI), calculated using the following equation (Equation 1):

$$LSI = \sum_{i=1}^n (W_i * R_i)$$

In the present work thematic maps were produced, related to the tectonic, lithology, roads, hydrographic network, the gradients and the orientation of slope (Fig.4, 5). The sub-headings which divided the information contained in each map are distinguished in Table 1. The maps containing linear elements, namely the map of tectonic lines, road and drainage network, were produced by defining buffer zones on either side of the ribbing to define classes.

Figure 6 presents the landslide susceptibility map as produced in accordance with the above, by using the weighted linear combination - W.L.C.

Table 1. The data layers and the weighting–rating system adopted in this study.

	Data layers	Classes	Weight	Rating
1	Lithology	Recent deposits (Holocene)	10	1
		scree		3
		marls		9
		limestone flat-pebble conglomerates		6
		limestones		10
		Dolomites		4
		schists		7
2	Tectonic Lineaments	Thrust (Buffer)	8	
		< 150m		10
		150-300m		8
		>300m		0
		Up-thrust (Buffer)		
		< 150m		7
		150-300m		5
		>300m		0
		Fault (Buffer)		
		< 100m		6
		> 100m		0
3	Road Network	Unsurfaced (Buffer)	7	
		< 50m		6
		> 50m		0
		Surfaced – Highway		
		< 50m		9
		50-100m		6
		> 100m		0
4	Stream Network	Class (Buffer)	8	
		< 50m		10
		50-100m		7
		> 100m		0
5	Slope Angle	>61°	9	10
		46-60°		8 (9)
		31-45°		6 (8)
		16-30°		4 (6)
		6-15°		2
		0-5°		1
6	Slope Aspect	W	6	9
		NW		10
		N		9
		NE		6
		E		4
		SE		2
		S		4
		SW		6
		Flat		0

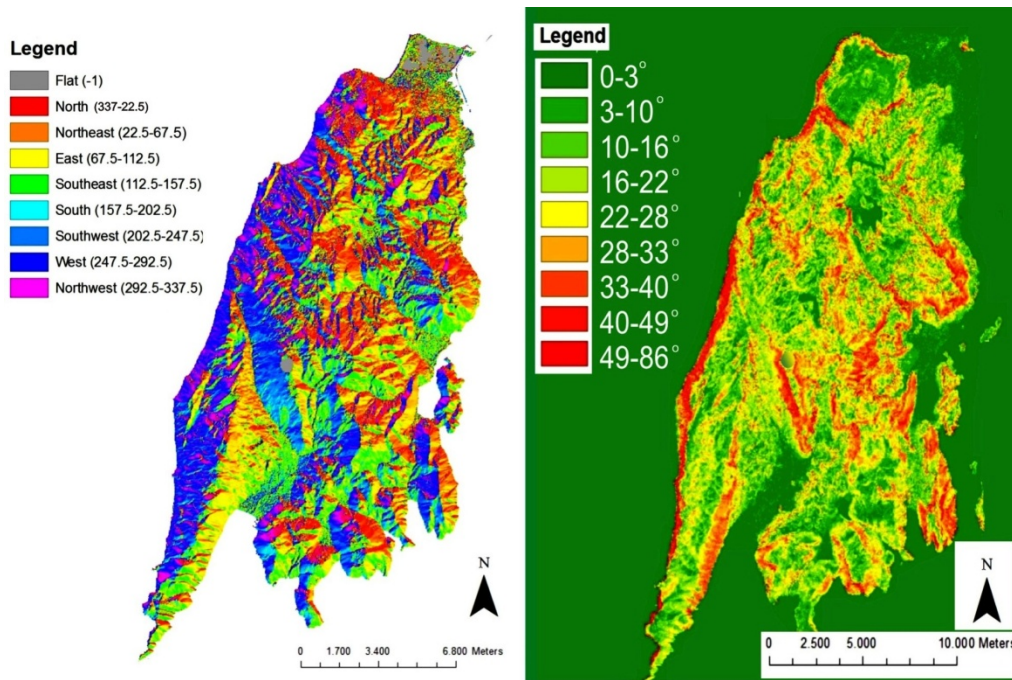


Figure 4: Thematic layers referring to slope aspect and slope angle

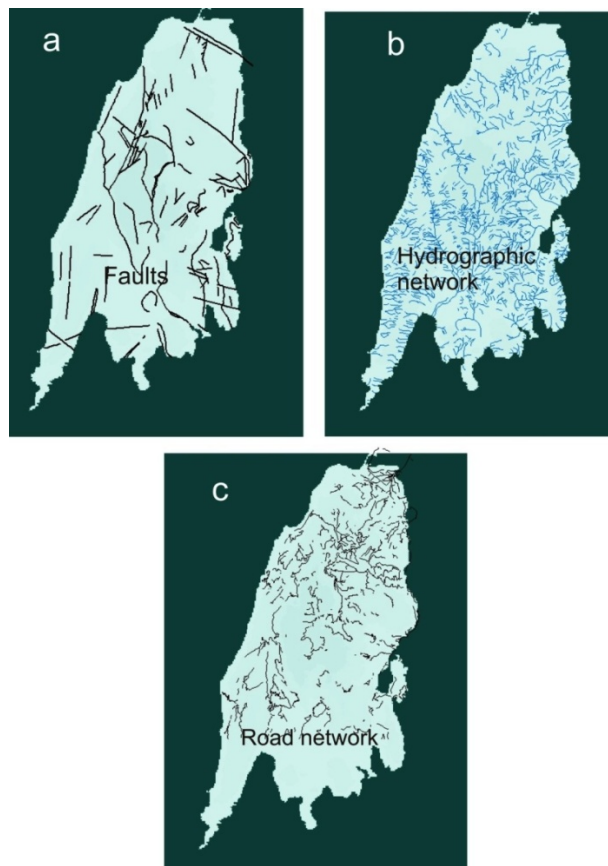


Figure 5: Thematic layers referring to: a) faults, b) hydrographic network, c) road network in Lefkada.

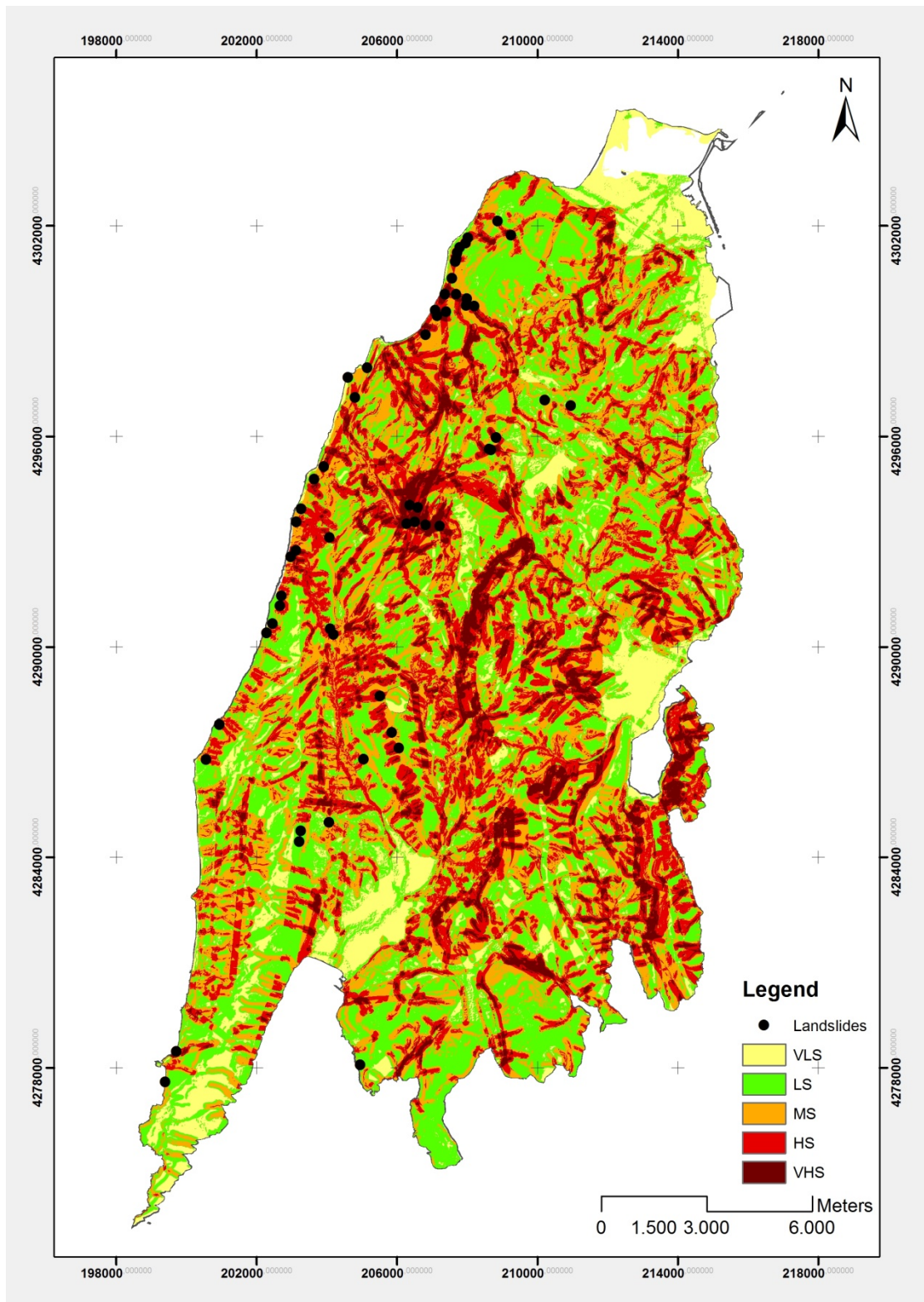


Figure 6: The Landslide Susceptibility Map produced by applying the weighted linear combination - W.L.C.

Validation of the method- prediction rate curve

In order to proceed to the validation of the landslide susceptibility map the prediction rate curves (Chung and Fabbri, 1999; van Westen et al., 2003; Kayastha et al., 2012, Sujatha et al., 2012) were adopted. According to this method the ratio of the area under the curve to the area of the whole chart was calculated. The curve which used for this reason presents the cumulative percentage of landslides according to the cumulative size of the landslide susceptibility zones containing them.

The incidence of landslides in each sensitivity zone gives the percentage of success and confirms how well the model predicts the landslide susceptibility (Chung and Fabbri, 1999). Thus, verify the effectiveness of the method. The wlc method shows 89% area under curve (fig.7).

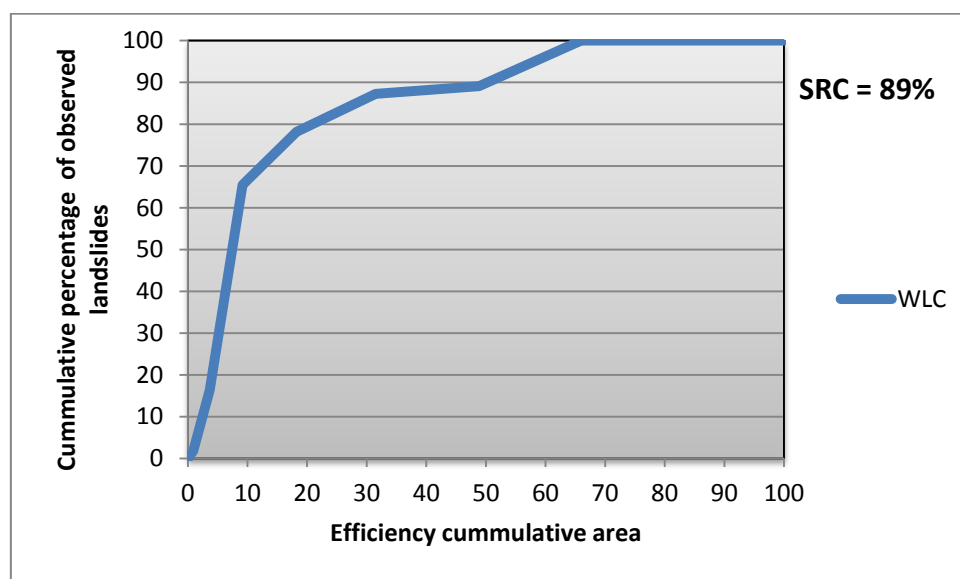


Figure 7: Prediction rate curve showing cumulative percentage of observed landslide occurrences versus cumulative percentage of decreasing landslide susceptibility index value

Conclusions

The validation procedure proved that the produced landslide susceptibility map is substantial for land degradation management and planning of the study area. Although the WLC methodology results vary depending on the subjective knowledge of experts, the results can be satisfactory, as the current study proved.

The high landslide susceptibility areas (red colour in the landslide susceptibility map) were expected to occur in areas which have vulnerable geological formations (marls, limestone and Neogene deposits) with extensive tectonic fragmentation, located on sections with intensive morphological relief, dense drainage and road network. Furthermore, as it was resulted by the overlaying of the spatial distribution of landslides with the thematic layers of slope aspect and slope angle, the highest frequency of landslides are related with west-and northwest-facing slopes and slope angle between 30–50°.

Thus, the landslide susceptibility weighting-rating system was set accordingly in order to point the expected high susceptibility areas. As presented in the susceptibility map, the majority of the landslides are located in high or very high landslide susceptibility areas.

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