ΕΚΤΙΜΗΣΗ ΤΗΣ ΕΠΙΔΕΚΤΙΚΟΤΗΤΑΣ ΚΑΤΟΛΙΣΘΗΣΕΩΝ ΣΕ ΕΘΝΙΚΗ ΚΛΙΜΑΚΑ ΚΑΙ ΠΡΟΚΑΤΑΡΚΤΙΚΗ ΑΝΑΛΥΣΗ ΔΙΑΚΙΝΔΥΝΕΥΣΗΣ ΕΦΑΡΜΟΖΟΝΤΑΣ ΥΠΟΛΟΓΙΣΤΙΚΕΣ ΜΕΘΟΔΟΥΣ ΣΕ ΠΕΡΙΒΑΛΛΟΝ ΓΠΣ

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Περίληψη

Στην παρούσα εργασία χρησιμοποιούνται τεχνητά νευρωνικά δίκτυα (ΤΝΔ) και ο στατιστικός δείκτης λόγος συχνότητας (ΛΣ) για την δημιουργία χαρτών εκτίμησης επιδεκτικότητας σε εκδήλωση κατολισθήσεων σε εθνική κλίμακα. Τα δεδομένα των φυσικών παραγόντων οι οποίοι χρησιμοποιούνται αντλούνται από εθνικές, ευρωπαικές και παγκόσμιες βάσεις δεδομένων. Αφορούν στο υψόμετρο, στο μέσο ετήσιο ύψος βροχής, στη λιθολογία, στην κάλυψη γης, και στην σεισμική επιτάχυνση. Οι φυσικοί παράγοντες ιεραρχήθηκαν, μέσω τεχνητών νευρωνικών δικτύων (ΤΝΔ), αυτοοργανούμενων χαρτών Kohonen (SOM) και γενικευμένων μητρώων αλληλεπίδρασης (ΓΜΑ). Η αξιολόγηση των αποτελεσμάτων έδειξε ικανοποιητική συμφωνία ανάμεσα στους χάρτες εκτίμησης κινδύνου και στη βάση δεδομένων συμβάντων εκδηλωμένων κατολισθήσεων, και για τις δύο μεθοδολογίες, με μικρή υπεροχή του λόγου συχνότητας. Τα αποτελέσματα των χαρτών εκτίμησης κινδύνου συνδυάστηκαν με στοιχεία υπό κίνδυνο γεωγραφικού υποβάθρου, (πυκνότητα πληθυσμού, δίκτυα μεταφορών, διοικητική διαίρεση), και χρησιμοποιήθηκαν ως στοιχεία εισόδου για μια προκαταρκτική ανάλυση διακινδύνευσης. Το αποτέλεσμα της ανάλυσης συμβάλλει στην ταξινόμηση των νομών της Ελλάδας και την αξιολόγηση των διαφορετικών τμημάτων του οδικού δικτύου ώς προς την αναμενόμενη επιδεκτικότητα σε κατολισθήσεις.

LANDSLIDE SUSCEPTIBILITY MAPPING IN NATIONAL SCALE AND PRELIMINARY RISK ANALYSIS APPLYING COMPUTATIONAL METHODS IN A GIS ENVIRONMENT

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Abstract

In the current paper, national landslide susceptibility maps were developed in order to recognize the most exposed regions, in Greece, using artificial neural networks (ANN) and the statistical index frequency ratio (FR). The physical factors, necessary for running the proposed models, are based on national, European and global datasets. These factors refer to landscape elevation, mean annual precipitation, lithology, land cover, and seismic acceleration. Through the use of Self Organizing Maps (SOM), ANN, and generic interaction matrix (GIM) the physical factors were ranked. This ranking is calculated in an objective and systematic approach. The verification of results showed satisfactory agreement between the susceptibility map and the landslide inventories for both methodologies, with a small prevalence of (FR) model. The results obtained from the landslide susceptibility model in integration with elements at risk, (i.e. population density, prefecture boundaries, and transportation network), were used as input for preliminary risk assessment analysis. The results of the preliminary analysis prioritized the prefectures and transportation network according to potential landslide susceptibility.

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Keywords: "*Landslides susceptibility mapping, Artificial Neural Network, Frequency Ratio, Geographic Information Systems, Landslide Risk Assessment".*

1. Introduction

In recent years, even though experience was accumulated in assessing and treating landslide hazard, our knowledge still remains fragmentary. Consequently, landslides and related instability phenomena in natural and manmade slopes remain an engineering geological problem to solve, and a natural hazard to confront. The study of landslide processes and mechanisms, as well as the rating of the critical physical factors is crucial for the selection of effective mitigation measures and the prediction of future events.

In order to estimate landslide susceptible areas for a given study area numerous methods (qualitative and quantitative) were proposed considering landslide causal factors. General overviews are presented in the work of (Carrara et al., 1999; Guzzetti et al., 1999). Qualitative mapping approaches, define landslide hazard by studying the distribution of the past landslide events. Usually the main criticism to geomorphological approach is the subjectivity related to expert evaluation and the difficulty for reproduction. In order to overpass subjectivity, computer algorithms were introduced through quantitative mapping approaches. Quantitative mapping approaches, involve the mapping and the statistical analysis of large number of parameters to derive a predictive relationship between the environmental factors and the occurrence of landslide events. Artificial neural networks are also very popular in landslide hazard assessment among others (Ercanoglu and Gokceoglu, 2001; Ermini et al., 2005; Melchiore et al., 2006). They offer a computational mechanism that can acquire, represent and compute a map by taking data from one multivariate space of information to another, given a set of landslide related data.

In Greece, landslides are a frequent natural hazard. In the last two decades, the landslide activity is relatively high as a result of increased urbanization and the development of transportation facilities, dams and reservoirs, industrial and urban activities, in landslide-prone areas. The continued deforestation, the wildfires and post-fire erosion processes, the climate change and the high potential for extreme weather conditions may also be a contributing factor.

In this study we apply SOMs ANN and FR methods, in order to produce landslide susceptibility maps across Greece with the use of landslide susceptibility index (LSI). Among the aims of this paper is the rating of the importance of the environmental factors related to landsliding. A preliminary risk analysis is also performed, by classifying administrative units and transportation infrastructure according to potential risk to landsliding.

2. Methodology

2.1 Study area and data preparation

The study was implemented in the mainland of Greece and the islands of Crete and Euboea (total area ~ 110000 Km^2. The landslide inventory is developed from IGME (Institute of Geological and Mineral Exploration) (Figure 1). The term landslide in this study obeys the definition given by Cruden and Varnes (1996) and Dikau et al. (1996), (used for soil, debris and rock travelling by sliding, flow and complex movement). Major rock fall events (a very common failure in Greece), are also included in the examined landslide inventory.

For the application of the proposed quantitative methods a spatial database with landslide related factors is developed. The considered environmental factors that influence the phenomenon were divided in three categories: topographic (slope, elevation), geological (seismic ground acceleration, lithology), climatic (mean annual precipitation) and anthropogenic (land cover). Elevation is obtained from a global database (SRTM-3, 2004) with moderate resolution data. Table 1 presents the properties and scale of the influencing factors used in this study. The evaluation and mapping of landslide hazard requires firstly the selection of the appropriate minimum mapping unit (MMU). The selection of MMU influences all the subsequent analysis and modeling procedure. In this paper the study area is represented through raster layers (grid format, - with cellsize 250 x 250m).

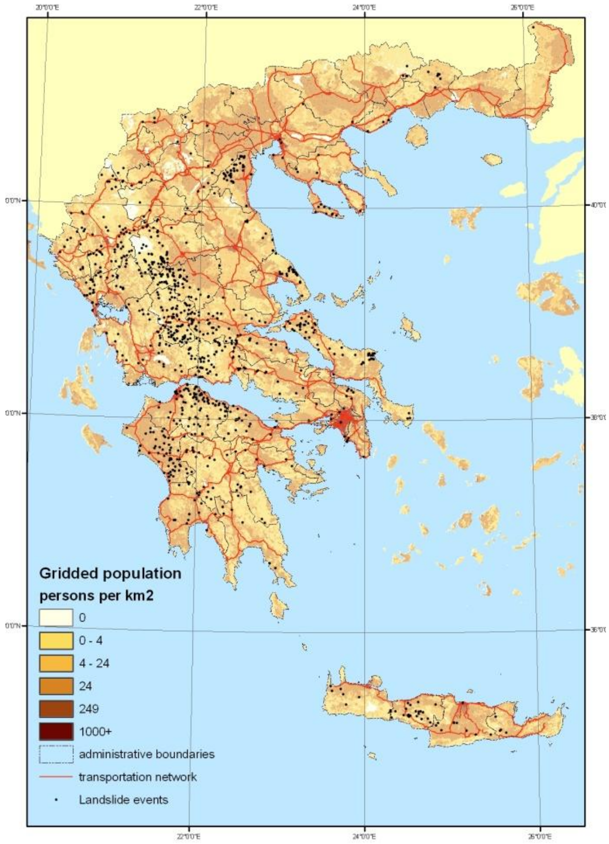

Figure 1. The study area with landslide events, and elements at risk

Table 1. *Data Layers of the study area*

Influencing factors		**type**	**cell size**
Topographic elevation	SRTM data	grid	250
Slope angle	DEM derived	grid	250
Seismic acceleration	Map of max horizontal ground acceleration, 1992 Technical Chamber of Greece	polylines	
Mean annual precipitation	Based on data from P.P.C. for the period (1950-1974)	polylines	
Geological formations	Geological Map of Greece, IGME	polygons	
Land cover	Corine Land Cover	grid	100
Landslide inventory	IGME	points	

3. Landslide Susceptibility and hazard mapping

3.1 Susceptibility mapping using frequency ratio (FR)

The Frequency Ratio (FR) statistical index, is the ratio of the area where mass landslides occurred in the total study area, and is also defined as the ratio of the probabilities of a landslide occurrence to a non-occurrence for a given factor (Lee and Talib, 2005).

Equation 1 shows the formulation of FR.

$$FR = \left(\frac{N_{I,J}}{A_{I,J}} \div \frac{N_T}{A_T}\right) = \frac{\text{Number of landslide pixel in subclass}}{\text{Number of landslide pixel in total area}} = \frac{\text{Density in subclass}}{\text{Density in map}} \quad (1)$$

Table 2 presents the relationship between landslide occurrence and each factor. Each factor was subdivided in a suitable number of relevant subclasses. Each grid data layer was reclassified according to FR value. Six data layers were overlaid to create a final landslide susceptibility map. Landslide susceptibility index (LSI) is calculated through the overlay function of the selected factors (Figure 2).

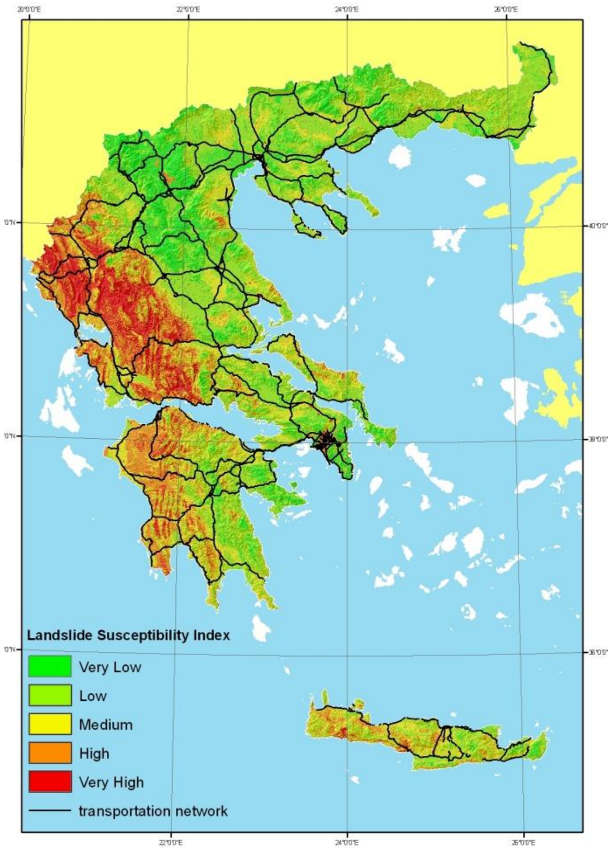

Figure 2. Landslide Susceptibility Index based on FR.

3.2 Susceptibility mapping using ANN

Landslide hazard evaluation was also performed by means of Artificial Neural Networks (ANNs) and Generic Interaction Matrix (GIM). This kind of analysis is aimed at coupling ANN and GIM to model the complex non linear relationships between landslides and influencing factors for landslide susceptibility zonation, in order to identify landslide prone areas.

Self Organizing Maps (SOM), which are unsupervised neural networks, were coupled with Generic Interaction Matrix (GIM), a methodology originally introduced by Hudson, (1991), which dictates a hollistic and synthetic hierarchic approach when interpreting engineering systems, such as natural or man-made slopes. Self organizing map, Kohonen (1995) is a special type of ANN that can learn from complex, multi-dimensional data and transform them into visually decipherable clusters. Basically, the SOM Toolbox, Vesanto, (2000) used in this study, is a visualization, clustering and projection tool. The scope of the application of this methodology, was the determination of the weights of the landslide influencing factors. The importance of the related factors, their dominance and interaction intensity, following Hudson (1991) definition, was also estimated. A systematic landslide inventory, Koukis and Ziourkas (1991), was manipulated through ANN and GIM, in order to determine the weights of the landslide causal factors.

Each raster layer representing an influencing factor was subdivided in a suitable number of relevant subclasses. Each subclass received different scores, based on a scale in which the highest mark corresponds to that category that has the highest contribution to landsliding. This coding is subjective and is taking into account the preexisting knowledge for landslides frequency in each subclass and results from statistical analysis performed in a data base of 802 events in the Greek territory (Koukis and Ziourkas, 1991). Overlay mapping of the weighted maps, was the next step. In this case, the map subclasses occurring ın each input map were assigned different scores (Table 2). Reclassified grids were produced according to different scores.

A very important visualization offered from SOM training algorithm through SOM Toolbox is scatter diagrams and histograms of all the parameters involved in the analysis. Scatter diagram can be coded and become a generic interaction matrix. A binary approach was followed in order to code the scatter diagram. Following this methodology a cause – effect diagram was produced. The cause effect plot refers to the influence of each parameter on the system and the effect refers to the influence of the system to the parameter. According to the applied methodology the most dominant parameters are, land cover, slope and mean annual precipitation. The most interactive parameters are land cover, and slope. For a more detailed presentation of this methodology the interested reader can refer to Ferentinou and Sakellariou (2005, 2007), where this methodology is presented. The relative weights calculated through SOM and GIM for the factors involved are presented in Table 3. The weighting values and the rating of the parameters combined with the rating of the subclass intervals of the parameters demonstrate the LSI for each map unit. The values of landslide hazard for each map unit are calculated as the product of parameter dominance multiplied by the reclassified grids.

According to the specific model the various thematic layers are superimposed in such a way that each map unit of the final map (Figure 3) takes its value according to weighing value of each factor and the score of the subclass interval. For the final product, landslide susceptibility index (LSI) for each map unit n is:

$$LSI = \frac{(w_1 item_1) + (w_2 item_2) + ... + (w_n item_n)}{n} \quad (2)$$

Where: w_1 to w_n are the weighting values according to ANN and GIM; $item_1$ to $item_n$ are the items of the data base for each reclassified parameter.

4. Validation of ANN and FR Models - Results

For better comparison of the susceptibility map hazard values were stretched in 0-1 with "1" value corresponding to maximum susceptibility value. The final output map for each approach was divided into five categories – implementing equal interval classification – in order to identify the following landslide hazard zones: very low – low - moderate – high – and very high (Figure 2 and Figure 3).

In order to validate the accuracy of each map the landslide inventory was compared to the produced LSI. The landslide susceptibility map produced according to frequency ratio (FR) model showed 86.75 % of the events coincide with medium to very high susceptibility class, in prediction accuracy of the total area of Greece. The ANN coupling SOM and GIM theory showed 83.22%. Accuracies of the two models can be evaluated relatively similar. The applied methodologies gave reasonable predictions. The areas of very high susceptibility are more or less located in the same parts of Greece for both methods. These areas are in the western and mountainous part of Greece (Pindos ridge and its south expansion in Peloponnese), in Crete and some other pockets across Greece mainland.

Table 2. *Frequency ratio and scores of the landslide influential factors*

Landslide Influential Factors	Parameter subclasses	Nr of landslide pixels in subclass	Nr of pixels in parameter subclasses	FR = Dens subclass / Dens Map	scores
Lithology					
1	Metamorphic formations	103	252848	0,71	2
2	Limestones	232	459608	0,87	3
3	Volcanic formations	26	95764	0,47	1
4	Marbles	17	89554	0,33	3
5	Schists	28	46556	1,04	2
6	Neogene	255	292441	1,51	6
7	Quaternary	90	382187	0,41	5
8	Flysch	281	196065	2,48	7
9	Molasse	11	33788	0,56	6
10	Shist cherts	46	26493	3,01	4
11	Terraces	2	7663	0,45	1
Land cover					
1	Artificial	79	41468	3,30	1
2	Agricultural	546	755208	1,25	3
3	Forest	199	361489	0,95	2
4	Little or no vegetation	265	702352	0,65	3
Slope angle (○)					
1	0-1	27	239533	0,19	1
2	1-2	36	122533	0,51	1
3	2-3	30	101948	0,51	1
4	3-6	108	268119	0,69	1
5	6-9	142	232500	1,05	2
6	9-12	157	205972	1,31	3
7	12-16	200	237149	1,45	7
8	16-20	169	183876	1,58	8
9	20-25	133	154001	1,49	9
10	>25	101	152109	1,14	4
Topographical elevation (m)					
1	0-100	105	335319	0,54	3
2	100-300	242	471924	0,88	3
3	300-500	178	259790	1,18	5
4	500-900	398	491887	1,40	5
5	900-1100	101	102408	1,70	4
6	1100-1400	59	136582	0,75	2
7	1400-1700	12	67949	0,30	1
8	1700-2874	2	23486	0,15	1
Seismic acceleration					
1	0,16g	452	753628	0,81	1
2	0,24g	639	677661	1,27	2
3	0,36g	3	34865	0,12	3
Precipitation (mm)					
1	338-675	155	860339	3,21	2
2	675-921	362	646720	1,03	4
3	921-1225	342	287659	0,49	5
4	1225-1603	190	87863	0,27	6
5	1603-2440	50	14980	0,17	7

Table 3. *Weights of influencing factors*

Influencing Factor	**Weights**
Land cover	1.71
Slope	1.64
Mean annual precipitation	1.64
Elevation	1.57
Seismic acceleration	1.42
Lithology	1.35

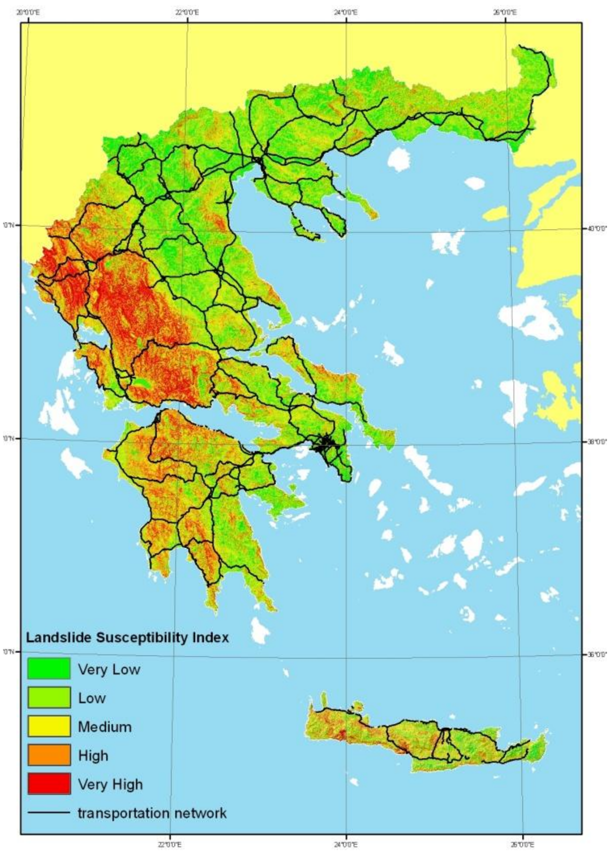

Figure 3 Landslide susceptibility index based on SOM – ANN.

5. Preliminary qualitative risk assessment

Based on the UN definition (UNDRO, 1979), risk is determined by three components: hazard (probability of occurrence), elements at risk and vulnerability. In this paper, a preliminary risk analysis is performed, therefore the aim the analysis is to highlight general trends, rather than come up with exact results. Risk refers to expected human or economic loss due to landslides, while vulnerability reflects "the degree of loss" (Coburn et al., 1991).

The elements at risk that were analyzed are the population density, transportation network, and the Greek administrative units (Figure 1). Transportation network was buffered at 100m and combined with LSI produced by FR model, which was slightly more accurate. According to the results of this overlay 1% of the transportation network is characterized to be in high and very high LSI zone. About 103km of total 10335km of transport network, are located in landslide prone terrain. The Greek prefectures were also combined, with FR LSI map. The study shows, that the following prefectures are mostly inside the landslide hazard hotspots: Ioannina, Aitoloakarnania, Achaia, Evrytania and Hleia. Several landslide prone areas in Greece were identified as being dangerous for the population after the combination of population density grid and LSI maps.

6. Conclusions

The development of landslide susceptibility maps in national scale is of great importance in planning agencies for preliminary hazard studies. In the current paper two methodologies are presented which produce LSI maps through statistical index and SOM. GIS technology, proved to be an indispensable tool for managing environmental factors, and to produce landslide susceptibility assessment maps. Landslide risk analysis even in preliminary level, can facilitate stakeholders, to select suitable locations for development schemes and plan mitigation measures in unstable landslide prone- areas. About 1%, of total of transport network, is located in landslide – prone terrain. Moreover, towns with population of a few hundred to a few thousands inhabitant is situated in the vicinity of landslide areas. The use of these results for specific local conditions is not recommended, as several uncertainties govern the data used in this study mainly attributed to scale. Much better agreement with landslide inventories could be achieved if the weighting of the parameters were calibrated and tuned to local conditions and even more factors could be implemented in the analysis in local scale.

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