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LANDSLIDE SUSCEPTIBILITY MODELS AT A REGIONAL SCALE. THE CASE STUDY OF THE REGION OF EPIRUS IN GREECE

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Abstract

The current study presents the results of a landslide susceptibility model applied in the Region of Epirus, Greece. For this purpose, a detailed record of 286 active landslides was created and the assessment of landslide susceptibility was based on the analysis of four predisposing factors (geology, slope angle, elevation, land use) and the application of the frequency ratio (FR) prediction model. FR is a statistical model of bivariate analysis that performs reliability tests on the results and is internationally accepted to quantitatively describe susceptibility. The final degree of landslide susceptibility was assigned through the landslide susceptibility index (LSI), which assumes that as the value of LSI increases, so does the susceptibility. In this way, five different susceptibility scenarios and associated maps were carried out for the study area, and all of them were evaluated for their ability to classify landslides in different susceptibility zones. Comparing the results, the most suitable model turned out to be the one in which all predisposing factors were included, as it had the highest percentage of landslides coinciding with the three highest susceptibility categories.

Key words

Landslide Susceptibility Index, Frequency Ratio, Regional scale, DEM, Land Use

1 Introduction

Landslides are quite common phenomena in Greece. According to the general landslide susceptibility map of Greece (Sabatakakis et al 2013) the largest part of Western Greece, that also includes the Region of Epirus, is characterized by “high” to “extremely high” susceptibility level. Some of the main predisposing factors that contribute to the occurrence of these landslides are geology, land use, elevation and slope angle. This study focuses on the investigation of the susceptibility of 286 active landslides in the Region of Epirus, as recorded in the field, with the evaluation based on the analysis of the relationship between the above four predisposing factors and landslide occurrence. The prediction model selected for this analysis was the Frequency Ratio (FR) and the final degree of susceptibility was assigned through the Landslide Susceptibility Index (LSI). Similar studies in Greece have been performed by Sabatakakis et al (2013), Ferentinou and Chalkias (2013), Kavoura and Sabatakakis (2020), and others. It is worth knowing that in the same Region, in the village of Metsovo, a pilot implementation of a permanent landslide early warning system has been set up (Depountis at al 2020).

2 Methods

2.1 Geological and geomorphological setting

The study area of the Region of Epirus extends over 9,203 km^2 and is characterized by a complex geological structure due to the Alpine orogen tectonics. The study area is structured by the formations of the Geotectonic zones (from east to west) Sub-Pelagonic, Pindos, Gavrovo and Ionian as well as postalpine formations (Papanikolaou 2021). The eastern part of the area is geologically occupied by the Geotectonic zones that are mainly composed of flysch, while the western and central part of the area is mainly made of limestone. These formations are strongly tectonized and often covered by a weathered zone of varying thickness, with the result that most of the landslides occur within these formations. The highest altitudes are observed along the mountain massif of Pindos, while the lowest altitudes are mainly in the west and south of the research area. It is noted that the highest altitude in the mountain massif of Pindos is 2,629m and 65% of the landslides examined are recorded in areas with an altitude >600m.

2.2 Landslide inventory

Recently, the Laboratory of Engineering Geology of the University of Patras created an online geodatabase platform, named as Hellenic Landslide Platform (He.L.P), providing information on landslides that have been recorded throughout Western Greece. According to the He.L.P. platform in the Region of Epirus have been recorded 286 landslides (Fig1). The classification of these landslides was based on that of Cruden and Varnes (1996) in which we observe that earth and rock flows are the most common type of movement (39%) into the study area, followed by complex landslides (21%) and rotational landslides (15%).

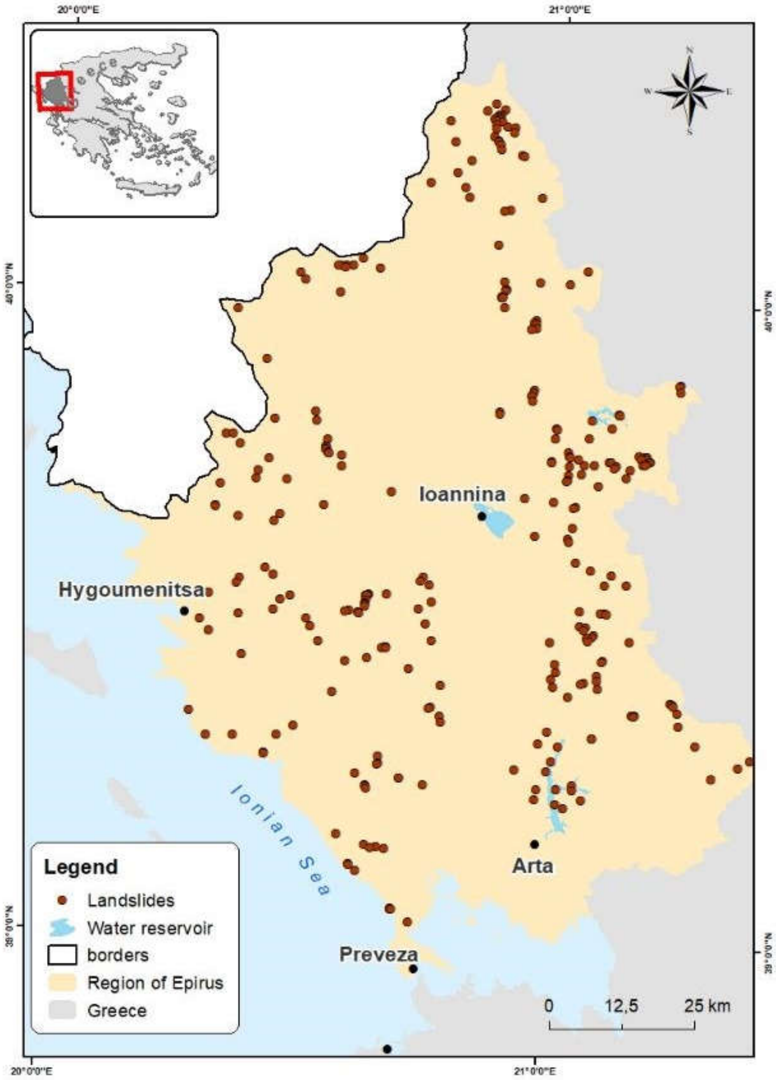

Figure 1. Landslide occurrences in the Region of Epirus, Greece

2.3 Predisposing factors

Four predisposing factors were chosen reflecting the general geological, geomorphological and environmental setting of the study area to access susceptibility. These predisposing factors were: a) Geology, based on an engineering geological mapping of a medium scale 1:50,000 (Fig2a), b) Elevation, in meters exported from a Digital Elevation Model (DEM) provided by the Greek Cadastral, with an accuracy of 5m (Fig2b), c) Slope inclination in degrees, calculated from a slope map with a pixel size of 5m (Fig2c), d) Land use, at an original scale of 1:100,000 provided by the Land Corine 2018 (Fig2d).

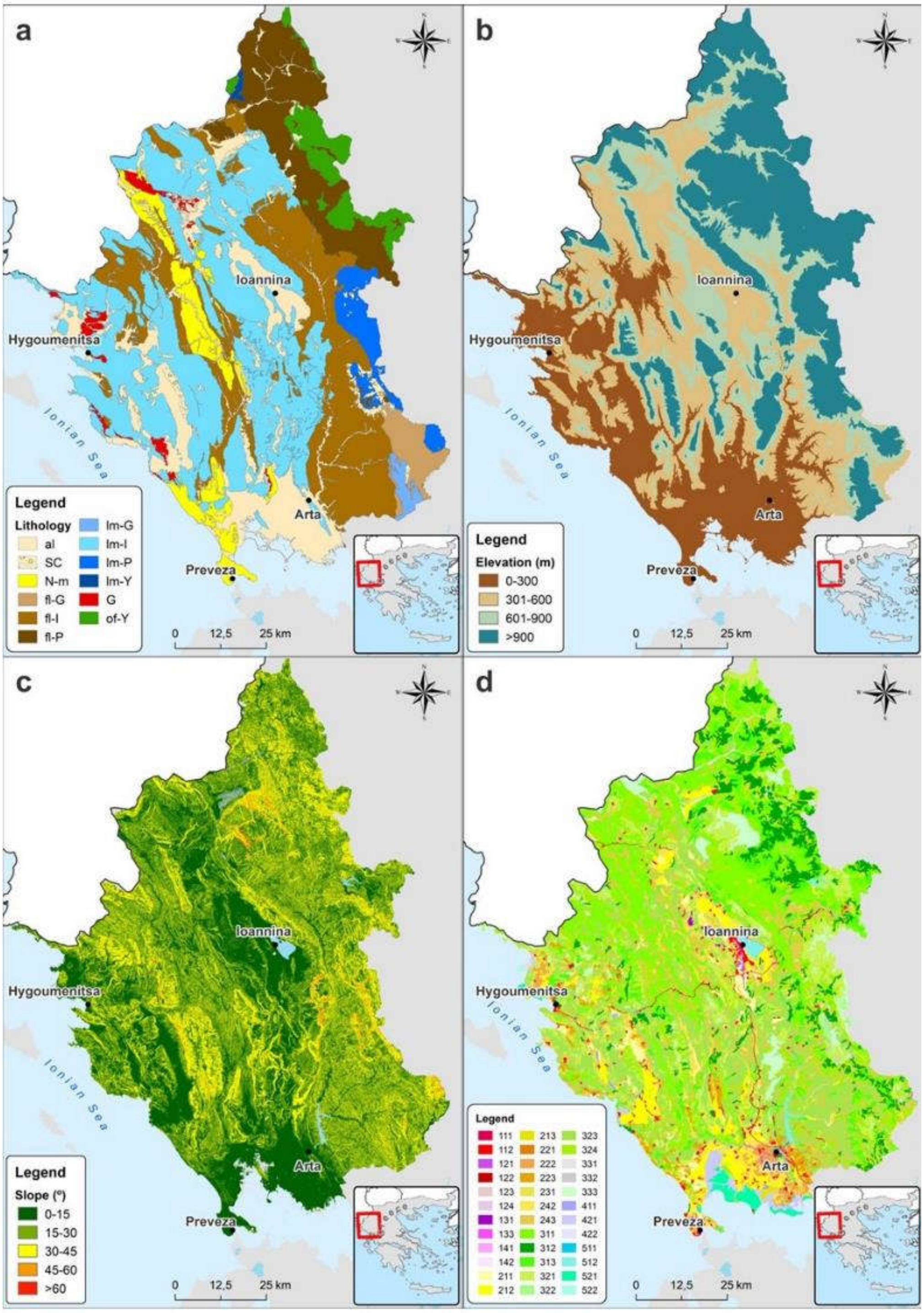

Figure 2. Landslise predisposing factors for the Region of Epirus, Greece a) Geology, b) Elevation, c) Slope inclination, d) Land use. The classes of all factors are presented in Table 2

2.4 Susceptibility model

In this work, the Frequency Ratio (FR) method was carried out for landslide susceptibility assessment. The FR model is a statistical approach based on the analysis between distribution of landslides and predisposing factors, in a specific area (Lee and Pradhan 2007). According to the method, the number of landslides in each class of each factor is calculated and the frequency ratio for each factor class is found by dividing the frequency of landslides by the area of each class (Lee and Talib 2005). If the ratio (FR) is greater than one (1), then the relationship between a landslide and the factor's class is strong, whereas if the ratio is less than one (1), the relationship is weak. The FR values were calculated for each class of the participated factors, by using the following equation (Eq. 1):

$$\mathrm{FR} = \frac{\mathrm{LF}}{\mathrm{CA}} \tag{1}$$

where LF is the relative frequency of landslides in a class of a factor and CA is the area (%) covered by the class of the same factor.

The Landslide Susceptibility Index (LSI) was estimated using equation 2 in the GIS environment:

$$\mathrm{LSI} = \sum_{j=1}^{n} \mathrm{Wij} \tag{2}$$

where n is the number of factors and Wij is the weight of each class i, of each factor j. The greater the index, the higher the landslide susceptibility.

This work provides an important opportunity to evaluate the reflection of the FR model, using different combination scenarios of four (4) predisposing factors. In the basic scenario (scenario 1) all factors participate, whereas in each subsequent scenario one factor is successively absent (Table 1).

Table 1. Suggested landslides susceptibility scenarios

Class	Scenario n.1	Scenario n.2	Scenario n.3	Scenario n.4	Scenario n.5
Geology	ü	ü	ü	û	ü
Land use	ü	û	ü	ü	ü
Elevation	ü	ü	û	ü	ü
Slope	ü	ü	ü	ü	û

3 Results

The FR model was applied to define weights for each factor, using the ratio of the percentage of landslides in a class of the selected factor to the percentage of the area of this class in the total area (Table 2).

Table 2. Classification of predisposing factors and their statistical weights

Factor	Class	Landslide frequency (Number)	(LF) %	Class area (CA) (km^2)	(CA) %	FR
Geology (Fig.2a)	Allouvial deposits (al)	21	7.34	1,357.92	14.82	0.50
	Scree (SC)	10	3.50	223.86	2.44	1.43
	Neogene formations (N-m)	23	8.04	517.24	5.65	1.42
	Flysch Gavrovo zone (fl-G)	9	3.15	209.70	2.29	1.37
	Flysch Ionian zone (fl-I)	103	36.01	1,914.35	20.89	1.72
	Flysch Pindos zone (fl-P)	72	25.17	961.32	10.49	2.40
	Limestones Gavrovo zone (lm-G)	0	0.00	70.35	0.77	0.00

	Limestones Ionian zone (lm-I)	37	12.94	3,129.2	34.15	0.38
	Limestones Pindos zone (lm-P)	4	1.40	289.38	3.16	0.44
	Limestones Sub-pelagonian (lm-Y)	0	0.00	16.25	0.18	0.00
	Evaporites (G)	1	0.35	119.6	1.31	0.27
	Ophiolites (of)	6	2.10	352.92	3.85	0.54

Elevation (Fig2b)	0 - 300 m	40	13.99	2,094.16	22.90	0.61
	300 - 600 m	64	22.38	2,481.38	27.14	0.82
	600 - 900 m	98	34.26	1,899.03	20.77	1.65
	> 900 m	84	29.37	2,668.93	29.19	1.01
Slope (Fig2c)	0^o - 15^o	58	20.28	3,204.51	35.50	0.57
	15^o - 30^o	115	40.21	3,644.41	40.37	1.00
	30^o - 45^o	80	27.97	1,956.88	21.68	1.29
	45^o - 60^o	31	10.84	202.39	2.24	4.83
	> 60^o	2	0.70	18.89	0.21	3.34
Land use (Fig2d)	Continuous urban fabric (111)	0	0.00	5.79	0.06	0.00
	Discontinuous urban fabric (112)	5	1.75	102.85	1.12	1.57
	Industrial or commercial units (121)	0	0.00	22.46	0.24	0.00
	Road and rail networks (122)	2	0.70	28.57	0.31	2.26
	Port areas (123)	0	0.00	0.70	0.01	0.00
	Airports (124)	0	0.00	9.85	0.11	0.00
	Mineral extraction sites (131)	0	0.00	1.85	0.02	0.00
	Construction sites (133)	0	0.00	2.32	0.03	0.00
	Green urban areas (141)	0	0.00	4.22	0.05	0.00
	Sport and leisure facilities (142)	0	0.00	173.30	1.88	0.00
	Non-irrigated arable land (211)	0	0.00	333.55	3.62	0.00
	Permanently irrigated land (212)	0	0.00	11.33	0.12	0.00
	Rice fields (213)	0	0.00	0.93	0.01	0.00
	Vineyards (221)	0	0.00	95.54	1.04	0.00
	Fruit trees and berry plantations (222)	4	1.40	158.49	1.72	0.81
	Olive groves (223)	0	0.00	65.59	0.71	0.00
	Pastures (231)	8	2.80	405.17	4.40	0.64
	Complex cultivation patterns (242)	54	18.88	898.66	9.75	1.94
	Land principally occupied by agric.. (243)	38	13.29	1,419.01	15.40	0.86
	Broad-leaved forest (311)	23	8.04	593.79	6.44	1.25
	Coniferous forest (312)	16	5.59	520.75	5.65	0.99
	Mixed forest (313)	20	6.99	932.59	10.12	0.69
	Natural grasslands (321)	0	0.00	31.44	0.34	0.00
	Moors and heathland (322)	48	16.78	1,632.09	17.71	0.95
	Sclerophyllous vegetation (323)	56	19.58	1174.77	12.75	1.54
	Transitional woodland-shrub (324)	0	0.00	37.68	0.41	0.00
	Beaches, dunes, sands (331)	1	0.35	22.73	0.25	1.42
	Bare rocks (332)	9	3.15	297.93	3.23	0.97
	Sparsely vegetated areas (333)	0	0.00	14.06	0.15	0.00
	Inland marshes (411)	0	0.00	83.39	0.90	0.00
	Salt marshes (421)	0	0.00	9.21	0.10	0.00
	Salines (422)	2	0.70	46.93	0.51	1.37
	Water courses (511)	0	0.00	76.09	0.83	0.00

Water bodies (512)	0	0.00	1.20	0.01	0.00

At the end, the Landslide Susceptibility Index (LSI) for the relevant landslide susceptibility mapping was estimated using the weights that were derived from the bivariate statistical analysis (Fig3).

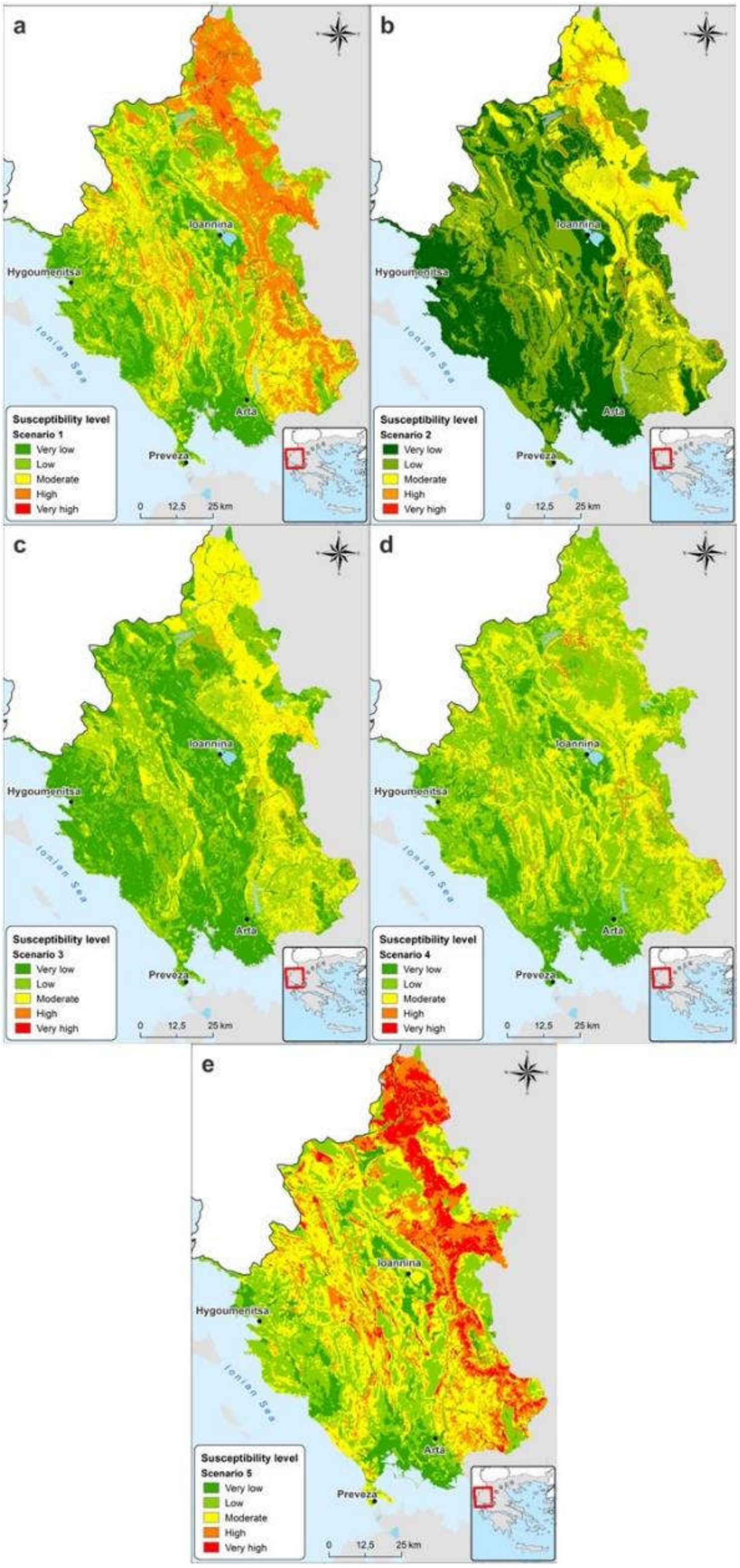

Figure 3. Lanslide Susceptibility Index mapping: a) scenario 1, b) scenario 2, c) scenario 3, d) scenario 4, e) scenario 5. The scenarios are presented in Table 1.

In all scenarios, the spatial distribution of LSI was categorized into very low, low, moderate, high and very high, susceptibility zones. After comparing the results, it turned out that scenario n.1, in which all factors are included, is the most suitable for the Region of Epirus, as it assigns up to 60% of landslides into the three most susceptible zones (Table 3). The final Landslide Susceptibility map created using the most suitable scenario n.1 is presented in Figure 3a.

Table 3. Percentage of landslides in susceptibility zones for each scenario

Class	Scenario n.1	Scenario n.2	Scenario n.3	Scenario n.4	Scenario n.5	Susceptibilty zone
1	1.7%	7.3%	7.3%	1.05%	0%	Very Low
2	12.9%	13.9%	29.0%	27.3%	14.0%	Low
3	25.5%	35.3%	49.6%	30.07%	29.0%	Moderate
4	48.2%	33.5%	8.4%	30.7%	22.4%	High
5	11.5%	9.7%	5.6%	10.8%	34.6%	Very High

4 Conclusion

The current study investigated the landslide susceptibility in the Region of Epirus, Greece. For this purpose, 286 active landslides recorded in the field were used as an inventory and four predisposing factors (geology, slope angle, elevation, land use) applied in a GIS framework in order to design four corresponding maps. Moreover, the frequency ratio (FR) equation was applied in the maps and the FR values were calculated for each class of the predisposing factors. The final degree of landslide susceptibility was assigned through the landslide susceptibility index (LSI), which assumes that as the value of LSI increases, so does the susceptibility. In this way, five different susceptibility scenarios were designed in a GIS framework and all of them were evaluated for their ability to classify landslides in the different susceptibility zones. In the basic scenario (scenario 1) all predisposing factors participate, whereas in each subsequent scenario one factor is successively absent. Comparing the results, the most suitable model turned out to be the one in which all predisposing factors were included, as it had the highest percentage of landslides coinciding with the three highest susceptibility categories.

In a next stage, the landslide susceptibility of the study area will be investigated in more detail by adding the precipitation factor with data derived from ERA5-Land. ERA5-Land is a gridded database with rainfall simulations derived from a subset of Global Climate Models (GCMs), developed under the CMIP6 projects, at a horizontal resolution of ~100 km and available for the continuous period 1971 - 2100 in the Copernicus Climate Data Store (C3S-CDS). For the region of Epirus, the GCMs of long-term climate projections/simulations will be downscaled to higher resolution (9-25km) using the gridded observation data with a spatial resolution 9-25km, available in C3S-CDS. This will improve the reliability of the susceptibility model in the study area, as rainfall is a predisposing and triggering factor in landslide occurrences.

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