Vulnerability Zonation Mapping for Landslides' Occurrence Using GIS and Remote Sensing Methodology: A Case Study in Northwestern Greece

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Abstract
This paper presents the creation of a landslide vulnerability map. The latter is developed using Geographic Information Systems (GIS) and Remote Sensing methods. Seven separate maps that include land cover, lithology, distance from road and hydrographic network, altitude, orientation and slope gradient in the study area, which is the Municipality of Pogoni in the region of Epirus, northwestern Greece, are created. Then, these maps are calibrated with weighting factors and combined with a linear method. In the final map, three landslide vulnerability zones, low, medium and high, are represented. The creation of this map may result in credible future location of infrastructure, identification of vulnerable spots and settlements and selection of the most appropriate and safer land use in the region.

Key words: landslide, vulnerability map, Pogoni, GIS, Remote Sensing

1. Introduction
"Landslides" are defined as the external or internal movement of a mass of debris, rock or earth down a slope (mountainside) (Cruden 1991). This terminology has been adopted by the Working Party on the World Landslide Inventory (Working Party on the World Landslide Inventory - WP / WLI 1991) and constitutes the most representative and widespread one among geologists and engineers investigating landslides worldwide.

The phenomenon of the movement of rocks, from a higher to a lower position, is primarily affected by the force of gravity. These rocks slide, after having their previous state of balance disturbed. Whenever the condition of the rocks is closely observed, the latter are never found to be in absolute balance. Subtle and principally influenced by the geological and climatic conditions of the region changes always occur. Such changes cumulatively alter the balance of the region to a great extent and then, due to the effect of gravity, landslides take place (Vasileiadis 2010).

1.1 Factors leading to landslide occurrence
According to the Working Party on the World Landslide Inventory (WP / WLI 1994), landslide occurrence is impacted by a range of factors. Some of these factors continuously affect a particular area while others do not, such as earthquakes, which

may, however, trigger a landslide. The most significant factors encompass the following (Koukis and Sampatakakis 2007):

- **Soil conditions:** The region, which is composed of weathered materials and variations in water permeability, stands several chances of having sensitive materials that may lead to the possible occurrence of landslides in the event of other factors' concurrent influence.
- **Geomorphological processes:** These processes are considered to be quite important and tend to appear both externally and internally in the geomorphology of the region. The effect of glaciers, the lifting of the region as a result of volcanic processes, rivers, water erosion at the base of a slope, as well as the removal of a region's vegetation cover due to fire or erosion may lead to the disturbance of balance.
- **Natural processes:** These processes may include fast snowmelt, soil erosion due to soil frost, volcano eruptions and earthquakes, prolonged or short-term heavy rainfall.
- **Anthropogenic processes:** Uncontrolled irrigation, excavations at the base of a slope, artificial deforestation, the use of landfills, quarries and mines as well as artificial ground vibrations stemming from vehicles and motor function, sometimes affect the region's balance heavily.

1.2 Classification of landslides

At times, various classifications have been proposed for landslides. A significant number of these classifications aggregate criteria, such as the materials' type, the form of the sliding surface, the speed of movement and the thickness of the mass that slid. The most widely accepted classification, extensively employed to describe all soil movements, is that of Varnes (1978). According to this classification, six basic types of movement are acknowledged:

- **Falls:** A mass of any size detached from a steep slope can slide bouncing or rolling, moving extremely fast (Fig. 1[a]).
- **Topplings:** During topplings the movement is rotational towards one or more units, around a pivotal point, which is lower than the mass' centre of gravity caused by gravity and the forces exerted by neighboring masses (Fig. 1[b]).
- **Spreads:** The movement prevailing in spreads is the one of lateral dilatation facilitated by shear flow (Fig. 1[c]).
- **Slides:** During slides the soil or rock mass moves downwards. The movement may be progressive, i.e. the shear fragmentation may not initially occur across the surface simultaneously, but it can be spread from a locally fragmented region. According to Varnes (1978), there are two types of slides, the rotational slides and the translational ones (Fig. 1[d] and 1[e] respectively).
- **Flows:** They usually appear on loose materials and the movable mass undergoes intense deformation (Fig. 1[f]).
- **Complex:** In general, landslides are a combination of some of the abovementioned types of movement either in the different parts of the

movable mass or in the stages of the movement process (Koukis and Sampatakakis 2007).

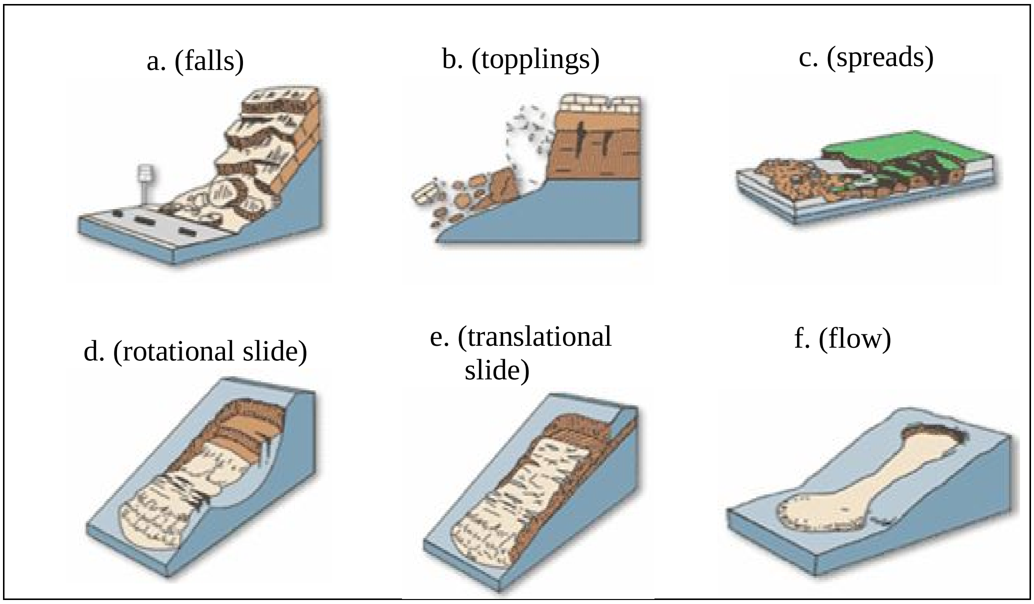

Figure 1: Types of Slides (Source: Margariti 2010)

1.3 Project purpose and objectives

Landslides are major natural disasters facing mountain areas. Although it is impossible to prevent natural disasters, their negative effects can be considerably limited through utilizing prevention strategies (Ercanoglu and Gokceoglou 2002). Aimed at the prevention of landslides' negative effects, research is conducted to identify the parts of regions where such phenomena are likely to occur. Consequently, the study and mapping of such regions can prove to be a useful tool for planning developmental strategies on mountain areas.

2. Study area

The study area is identified as the Kallicratic Municipality of Pogoni in the region of Epirus (Fig. 2). The area encompasses the municipal units of Ano Kalamas, Ano Pogoni, Delvinaki, Kalpaki, Pogoniani and Lavdani (Law 3852/2010).

The area is included in the country's mountainous municipalities (Law 3852/2010). It is equally shared into lowland and mountainous parts, with the highest peak being that of Mount Nemertsika, exemplifying an altitude of over 2000 meters. The area may be sensitive to landslide issues both due to high mountains mostly in the north parts, which are characterized by high gradient slopes, and due to lithology (rocks prone to phenomena of sliding).

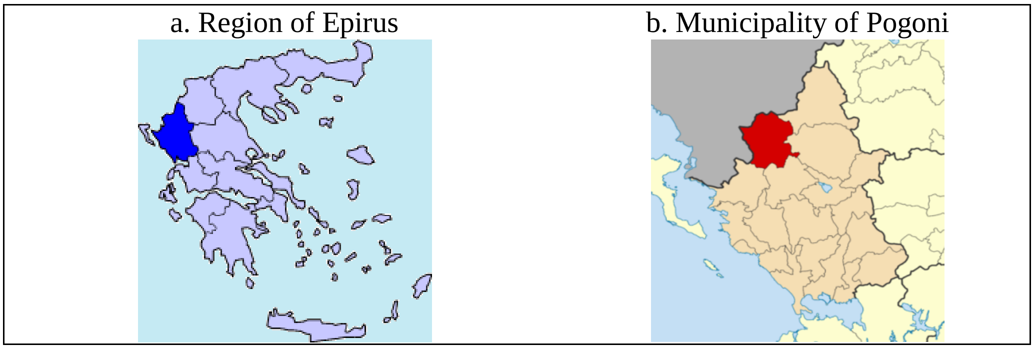

Figure 2: (Source: Wikipedia – Retrieved July 13, 2014 from http://el.wikipedia.org/wiki/%CE%89%CF%80%CE%B5%CE%B9%CF%81%CE%BF%CF%82)

The rocks present in the area covered by the Municipality of Pogoni are mainly limestone, shale and flysch while alluvial deposits are also noticed in small concentrations. Limestone displays satisfactory geomechanical indices and is not quite prone to phenomena of sliding. On the other hand, slate, to a more limited extent, and flysch and alluvial deposits, to a greater extent, are characterized as ideal rock formations for slope failure (Fytrolakis 1990).

It is also worth pointing out that the hydrographic network of the region is fairly rich, a fact that may cast a negative effect, eroding terrain, soil and subsoil, in the event of landslides.

3. Technologies for the development of landslide hazard map

Landslides are a phenomenon related to a host of negative effects, especially in mountainous areas. The development of technology and the ease of observing earth from the top have provided scientists with the opportunity of using Geographic Information Systems (GIS) and Remote Sensing techniques to capture spots and areas that may face landslide problems in the near or distant future quite accurately. Through the creation of landslide vulnerability maps, vulnerability zones are established in the region, taking into consideration several factors and variables.

3.1 Data collection and processing

To produce the final vulnerability map, the following seven factors, deemed important for causing or likely to cause landslides to the region of Pogoni (Budetta et al. 2008; Galanos and Kolokoussis 2010; Kouli et al. 2010; Yalcin et al. 2011), were identified:

- Slope gradient
- Land covers
- Lithology
- Distance from roads
- Distance from hydrographic network
- Altitude
- Slope Orientation

The identification of land covers has been achieved through a remote sensing method. An image (raster) of the Landsat 5 satellite, receiver TM (13/08/2011), of the greater region of Pogoni has been analyzed via the satellite digital illustrations' supervised classification of the minimum distance technique. In other words, the selection of the major land covers was dependent on the color combinations of the color composite.

To determine the region's lithology, 1:50,000 geological maps of the Doliana, Tsamantas and Vasiliko-Pogoniani (Koukouzas and Perrier 1968) regions, borrowed from the Institute of Geology and Mineral Exploration (IGME), were taken advantage of. These maps were precisely adjusted to the boundaries of the Municipality of Pogoni and then the digitization of major rocks in the area was performed.

For the road and hydrographic network, vector models, representing the main roads and hydrography (rivers and lakes) of the region, were employed.

The altitude, orientation and slope gradient were estimated through the digital terrain model (GDEM) of the region of Pogoni and the application of the necessary illustration filters to it.

4. Methodology

The abovementioned factors correspond to individual vulnerability maps that were created after their characteristics have been calibrated. Then, they were linearly combined to obtain the final map (Tab. 1).

4.1 Calibration of the factors

The calibration of each factor was based on relevant work carried out in an environment displaying similar lithological background to the one of the study area (Galanos and Kolokoussis 2010). Level 1 corresponds to a very low likelihood of landslides, while Level 6 is tantamount to exceptionally high probability. In table 1, the individual calibrations are illustrated.

Table 1: Calibration of the factors' characteristics

Factor	Characteristics	Vulnerability level
Slope gradient (in minutes)	0-4	1
	5-9	2
	10-14	3
	15-19	4
	20-29	5
	>=30	6
Land covers	Forests	1
	Grassland	2
	Fallow land	3
	Crops	5

Table 1 (sequel): Calibration of the factors' characteristics

Factor	Characteristics	Vulnerability level
Lithology	Limestone	1
	Slate	3
	Flysch	4
	Alluvial deposits	5
Distance from roads (in meters)	>=60	1
	40-59	2
	20-39	3
	0-19	5
Distance from hydrographic network branch (in meters)	>=60	1
	40-59	2
	20-39	3
	0-19	5
Altitude (in meters)	0-399	1
	400-599	2
	600-999	3
	1000-1499	4
	>=1500	5
Slope orientation (in minutes)	0-44	3
	45-89	2
	90-179	1
	180-224	2
	225-269	3
	>=270	4

4.2 Creating intermediate thematic maps

For each factor a three level, thematic map of vulnerability zones, containing the calibration coefficients of individual characteristics, was created. In figures 3 and 4, vulnerability zones, taking into consideration slope gradient and altitude, are displayed. Using the digital terrain model, emerged the vulnerability maps as a result of slope gradient and altitude respectively, showing consideration for similar vulnerability levels. For the land covers map (Fig. 5) the technique of classifying the minimum distance has been employed and in the figures to follow the risk profile of the soil is illustrated.

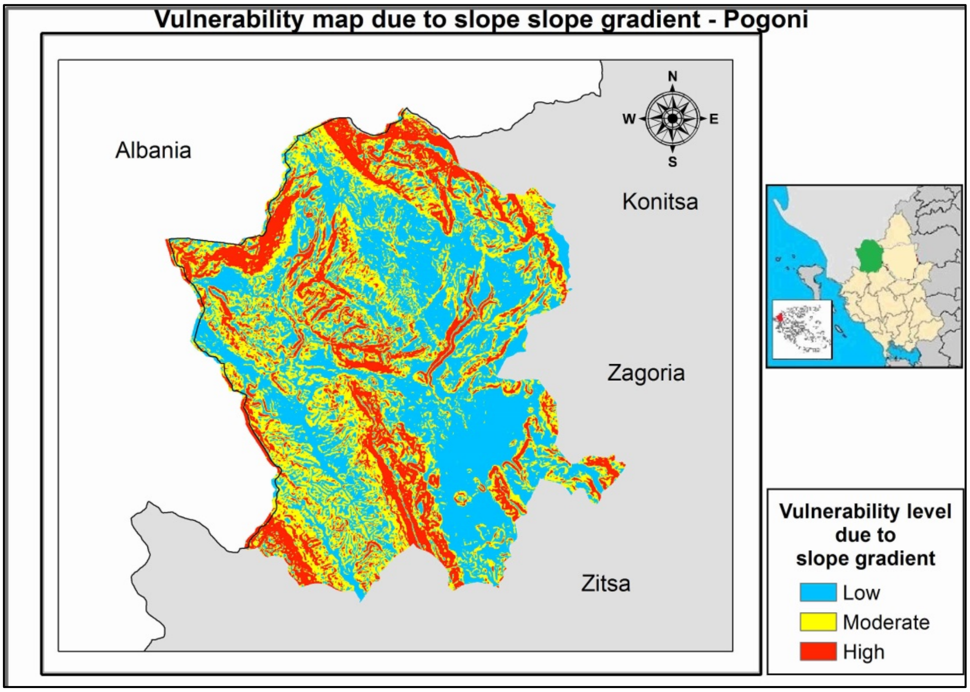

Figure 3: Vulnerability map due to slope gradient

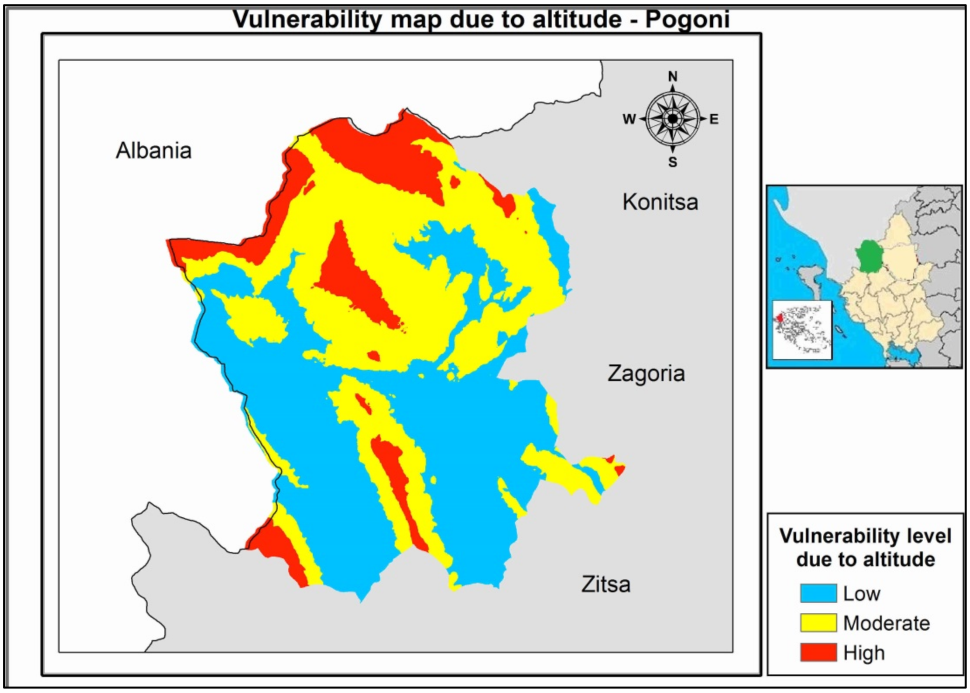

Figure 4: Vulnerability map due to altitude

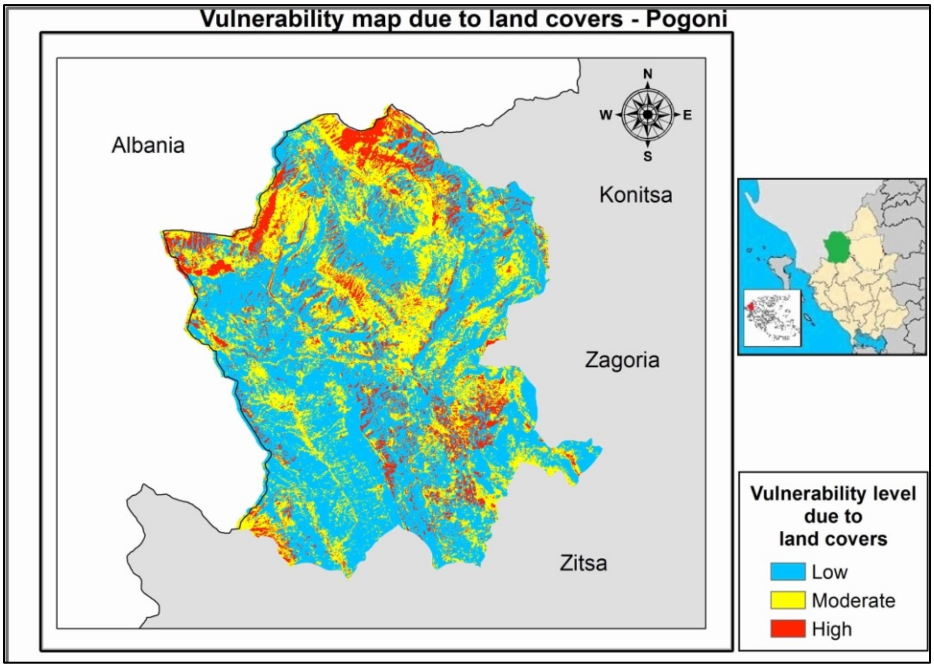

Figure 5: Vulnerability map due to land covers

In the vulnerability map considering lithology (Fig. 6) the graded lithologic sensitivity is illustrated. For the vulnerability maps associated with the road and hydrographic network of the region were identified individual distance zones. The closer the network is a zone the greater the likelihood of landslides.

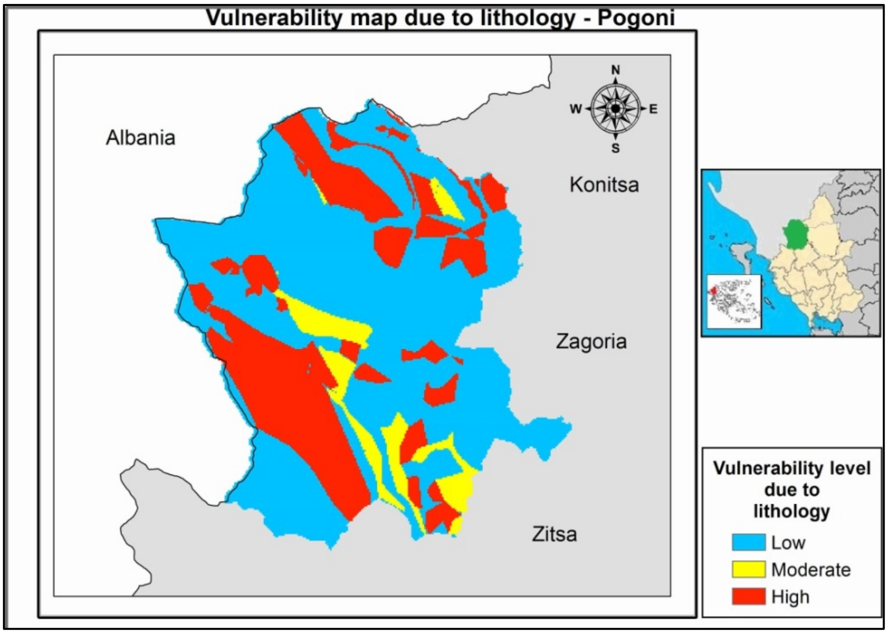

Figure 6: Vulnerability map due to lithology

5. Final landslide vulnerability map production

5.1 Linear combination of individual thematic maps

For the seven sub-factors, weighting coefficients, depending on their vulnerability to landslide occurrence, are provided. Each factor influences the risk of landslide occurrence to a different extent. The weighting degree of each factor was founded on relevant work carried out in an environment displaying similar lithological background to the study area (Galanos and Kolokoussis 2010). The highest weighting coefficients appear in the slope gradients, the land covers and the region's lithology. In table 2, all factors and their weighting coefficients are illustrated.

Table 2: Weighting coefficients of the factors

Factor	Weighting coefficients	Percentage
Slope gradient	0,35	35%
Land covers	0,2	20%
Lithology	0,15	15%
Distance from road	0,1	10%
Distance from hydrographic network branch	0,1	10%
Altitude	0,06	6%
Slope orientation	0,04	4%

Next, the seven individual maps are placed into the linear function (1), to provide the cumulative vulnerability map:

$$R_\alpha = \sum W_i X_i \qquad (1)$$

R_α = landslide risk in the ***a*** pixel,
W_i = the weighting factor of agent ***i***,
X_i = the value of the factor ***i*** risk level in the ***a*** pixel

5.2 Final landslide vulnerability map

The final map is the result of the reclassification process of the cumulative vulnerability map and illustrates three landslide vulnerability levels (Fig. 7). The light blue color represents the low risk regions, the yellow one stands for the moderate risk regions while the red colour corresponds to high risk of landside occurrence regions. Furthermore, the percentage of the study area occupied by each vulnerability zone is also included.

Finally, to test the results, six regions, where landslide problems appeared in the past, had been mapped and it was found that these regions (Kakolakos, Merope, Kefalovrysso, Agia Marina, Lavdani, Vristovo) fall into the high and moderate risk categories.

In figure 8 in the Appendix, the abovementioned steps, from the collection and processing of data to the creation of the final landslide map, are delineated. The flowchart assists in better reflecting the steps followed and by means of this tree representation the linear combination of the data employed is more exhaustively illustrated.

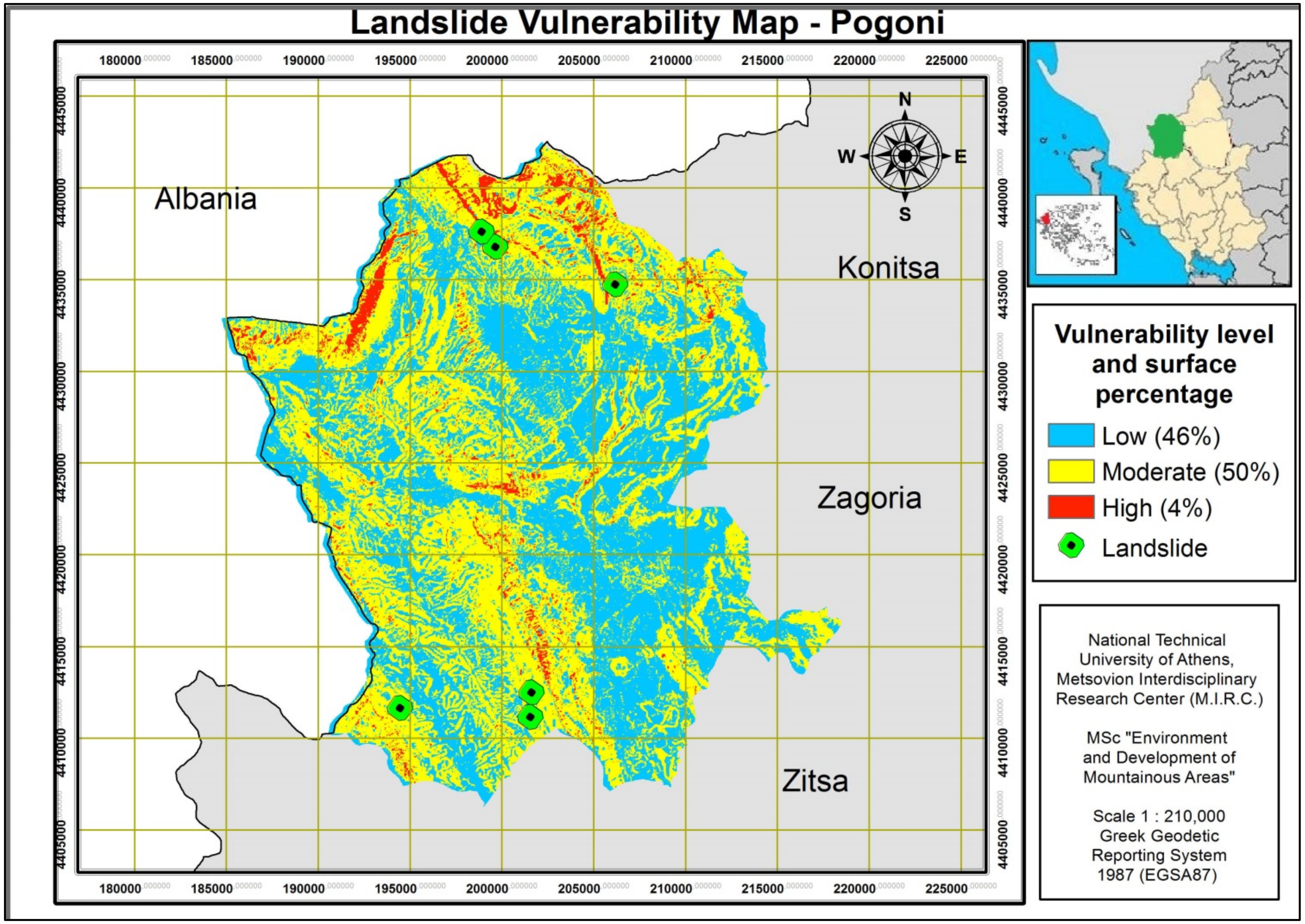

Figure 7: Landslide vulnerability map for the Municipality of Pogoni

6. Comparison to other regions in Epirus

The results of the final vulnerability map, using Geographic Information Systems (GIS) and Remote Sensing, as well as the collection of information on landslide problems in the Pogoni region, reveal that, much of the region is characterized by a low degree of risk. Considering data research for landslides in the areas of Metsovo (Farmakaki 2011) and Zagoria (Verroiou and Stergiou 2013) it is found that, as illustrated in diagram 1, the area of Pogoni shows signs of lower landslide rates when compared to two neighboring regions.

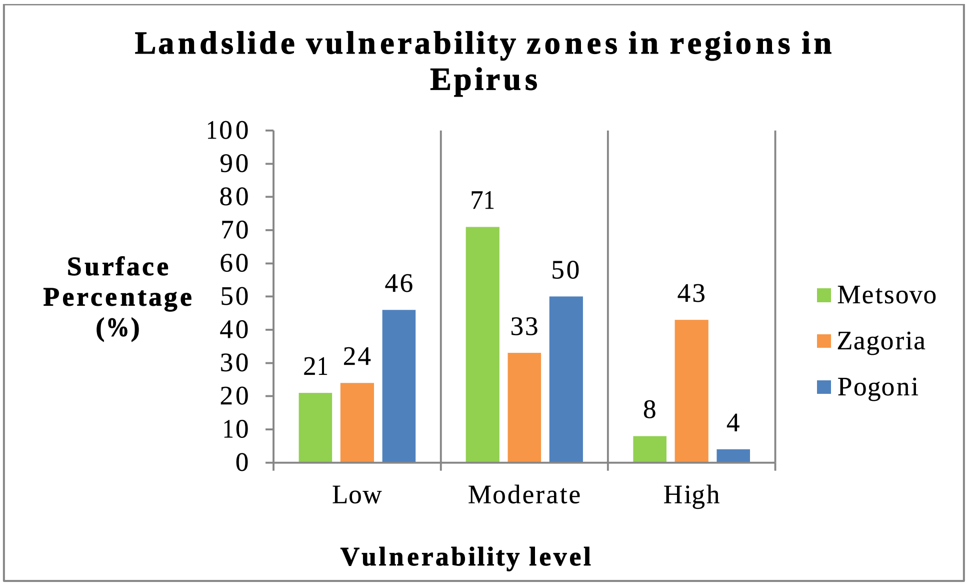

Diagram 1: Comparison of landslide vulnerability zones in regions in Epirus

This is largely due to the fact that the region of Pogoni is more extensively covered by lowlands, compared to the regions of Zagoria and Metsovo. Steep slope gradient of the study area occupy less area than that of neighboring municipalities of Metsovo and Zagoria. Besides, the study area's coverage with limestone (which is not prone to rock sliding phenomena) is greater in comparison to the one in the other two locations. These features are inhibiting factors regarding landslide phenomena.

This finding is highly positive for the region of Pogoni, because in a region of Greece, such as Epirus, faced with major landslide difficulties, in municipality of Pogoni high degree of risk appears in small areas. This will facilitate the sitting of infrastructure for various types of land use not to be obstructed and generally increases local residents' sense of security concerning natural hazards.

7. Conclusions and issues for further study

Through the methodology applied, the identification of risk areas can be accomplished at a fairly low search cost. This research may benefit planners, engineers and other scientists which providing guidance for the development of a region and for planning technical works. However, in the event of an area being referred to as of high risk on the landslide vulnerability map, the former should be thoroughly mapped by specialists geologists/geotechnical workers (high cost research). This way, information concerning vulnerability mapping can be interbred with the in situ examination of the region, in view of safer conclusions.

In addition, the present research work enables the use of similar methodologies in different issues for a different research area. Technical services, engineers, agronomists and qualified personnel related to the human and geoenvironment interaction in general, can export more reliable and accurate records of individual specific conditions of their region, through interoperable GIS applications and Remote Sensing methods, to better exploit the natural resources of their place and resolve other problems. Such applications may include precision agriculture, soil erosion control, surface water pollution control, detailed analysis of land and fire forest vulnerability mapping.

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Appendix

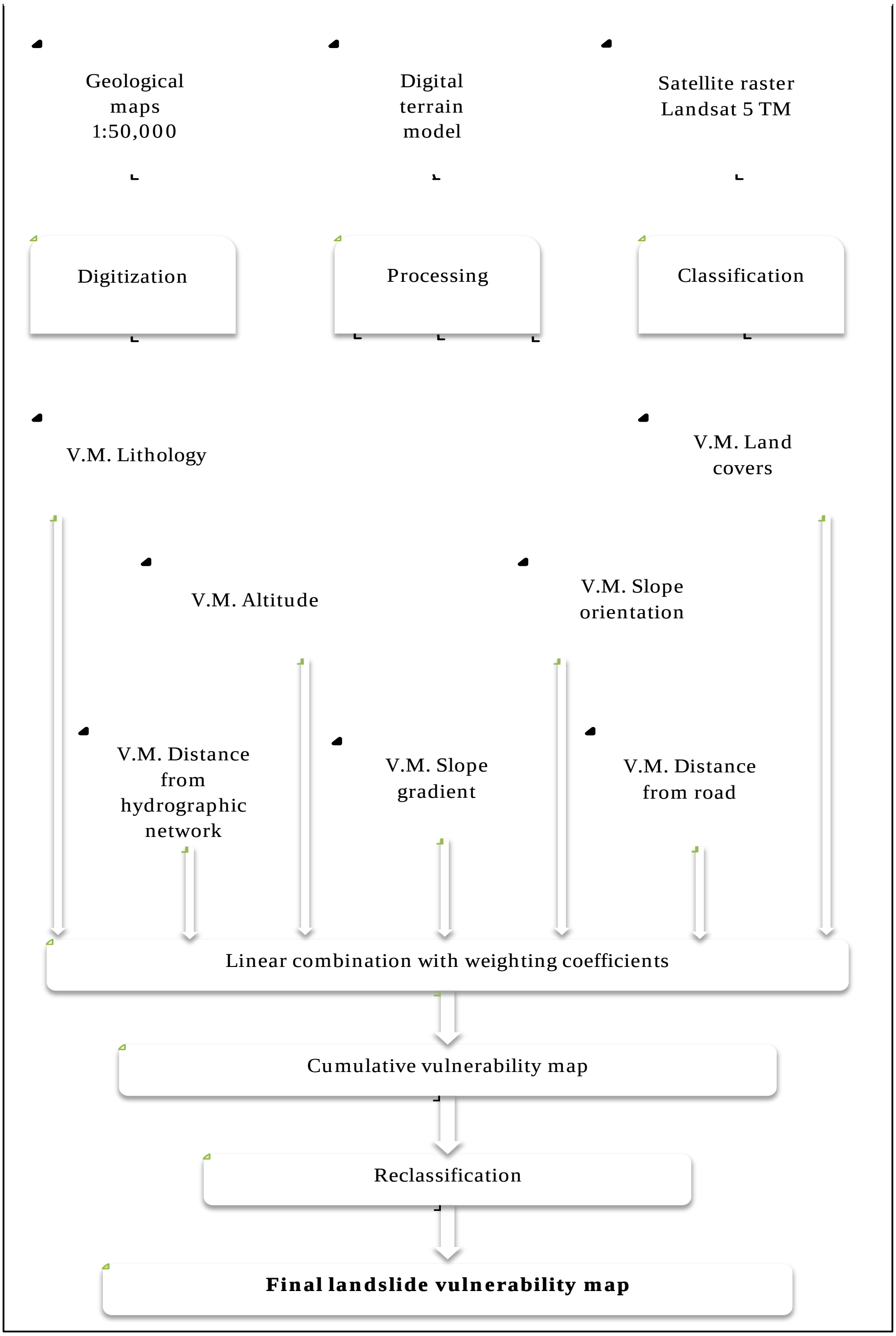

Figure 8: Flowchart for the development of vulnerability zonation map for landslide occurrence