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ASSESSMENT OF THE VULNERABILITY DEGREE OF DIFFERENT LITHOLOGICAL FORMATIONS IN THE CATCHMENT AREA OF AGIA EIRINI GORGE, WESTERN CRETE

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Abstract

This paper presents a methodology for assessing the degree of vulnerability of different lithology formations constituting the drainage basin of the gorge of Agia Eirini. The methodology is based on the processing of spatial aspects parameters of lithology, hydrography, geomorphology and the vegetation cover, which are related with the weathering impact on formations either directly or indirectly.

Initially a series of primary spatial data on geology, topography, the river network and the land use in the region, were used to produce thematic maps. These maps include the geological map, the digital terrain model (DTM), the map of the land use, and hydrographic maps of density and frequency. By processing the data according to their role in enhancing the vulnerability of formations, the data were determined and the following thematic maps: "Map of geological formations susceptible to weathering", "Map of hydrographic texture", "Map of morphological inclinations" and "land use map protecting against the loss of disintegrated material were produced. By appropriate combination of these secondary data, areas of vulnerability of formations were recorded which are shown on a final thematic map. This information is particularly valuable in the management planning and gives the opportunity to evaluate and predict the impact of various proposed projects or future scenarios. They can also be used to identify positions to take necessary measures to protect areas at high risk of loss of material.

Key words: *vulnerability, drainage basin, weathering, Agia Eirini gorge, West Crete*

1. Introduction

Management planning of natural resources is a necessity nowadays. In this context with the possibilities offered by modern information systems, a methodology for assessing the vulnerability of the formations constituting the drainage basin of the gorge of Agia Eirini was implemented.

In recent years, the increasing development of Geographical Information Systems (GIS) has provided powerful tools for the collection, storage, analysis and presentation of geographically oriented data. The possibility of management of such georeferenced data has made the GIS a powerful decision support tool.

We set up a database for the drainage basin of the gorge of Agia Eirini. By processing spatial aspects of lithology, hydrography, geomorphology and the vegetation cover, we assessed the vulnerability of the formations constituting the catchment area of the gorge. Lithology, hydrography, geomorphology and the vegetation cover are different parameters related to weathering. The analysis of their significance and the appropriate combination of those parameters provided a thematic map of the vulnerability degree of the formations.

The gorge of Agia Eirini is located on the west side of the White Mountains (Fig. 1). It belongs to the Selino province of the Chania Prefecture. The gorge is one of the most famous gorges of Crete and is a multiply protected area (part of the "White Mountains" National Park, "Natura 2000 Area", "Important Bird Area" and "Special Protection Area"). It consists of metamorphic carbonate rocks of the Trypali unit, a formation of Triassic age, and the Phyllite unit formations.

2. Geological setting

Today, the island of Crete is located north of the Hellenic trench. The geological framework consists largely of nappes of contrasting lithologies and metamorphism that were stacked southwards during an Oligocene to early Miocene N-S compression. Most of the whole nappe stack of continental Greece is recognized in Crete. It has however a reduced thickness and more important shortening. The nappes are stacked from top to bottom, i.e. from the most internal to external units in the following order: Asterousia nappe, Miamou nappe, Arvi nappe, Pindos-Ethia nappe, Tripolitza nappe, Phyllite nappe and Trypali nappe. The Plattenkalk Group represents the lowermost known tectonic unit beneath the nappe pile of Crete and their formation has been involved in the tectonometamorphic process during the Oligocene-Miocene.

The complexity of the geological structure and access difficulties, due to the high topographical relief and thin infrastructure, are the main reasons that in Western Crete, the existing geological maps are dated back in the 1960's; whilst for some parts, as the area of Palaiochora the basic geological map has just been published. Although a number of geoscientists have worked and published papers regarding the wider area (e.g. Manutsoglu et al. 1999; 2001; 2003), the gorge in particular has recently become subject of systematic studies (Bizoura et al. 2004; 2006).

According to these researchers, on the map region, apart from the Quaternary and Neogene sequences, parts of the Tripolis series are found, consisting of Jurassic and Cretaceous limestone, eastern of the southern end of the gorge. On the northern and western part of the region, grey and white dolomitic marbles appear, containing a characteristic bituminous horizon of 2-3 m thickness, which are tectonically positioned over the underlying formations. The marbles are locally similar to the crystalline Plattenkalk limestones, but without flints. These are the Trypali unit limestones (Creutzburg & Seidel, 1975), of no later than Middle Triasic age, the geotectonical position of which is known (always thrusted over the Plattenkalk group) but their paleogeographical position is unknown and has been subject of long scientific controversies.

The underlying unit is build by rocks of the Plattenkalk-Group. The first detailed lithostratigraphical description, which revised the dating on the geological map (Carboniferous-Perm), was prepared by Fytrolakis (1980) and was supplemented by Soujon et al. (1998).

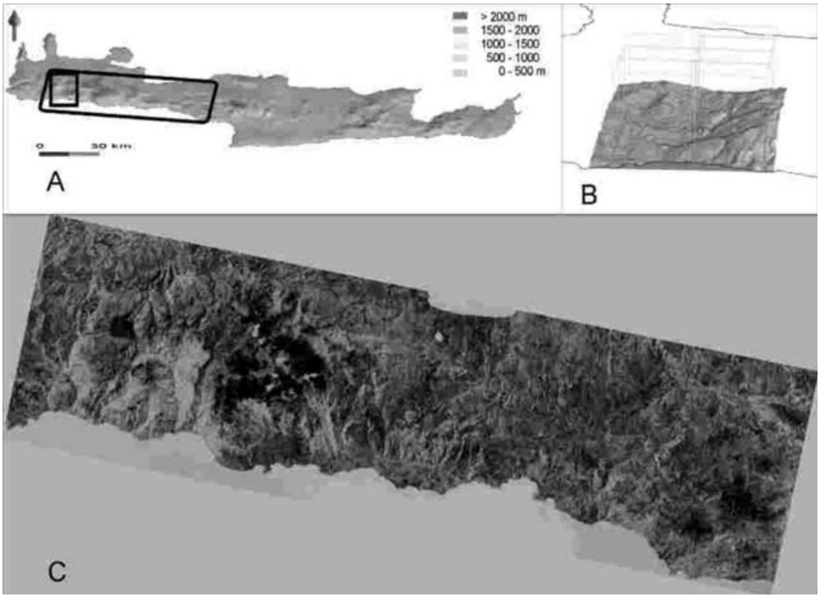

Fig. 1: A: Geographical position of the study area. B: Projected orthophoto maps of the study area& C: Landsat - TM (Scene 182-35, UTM Zone 35, Zones 742 RGB).

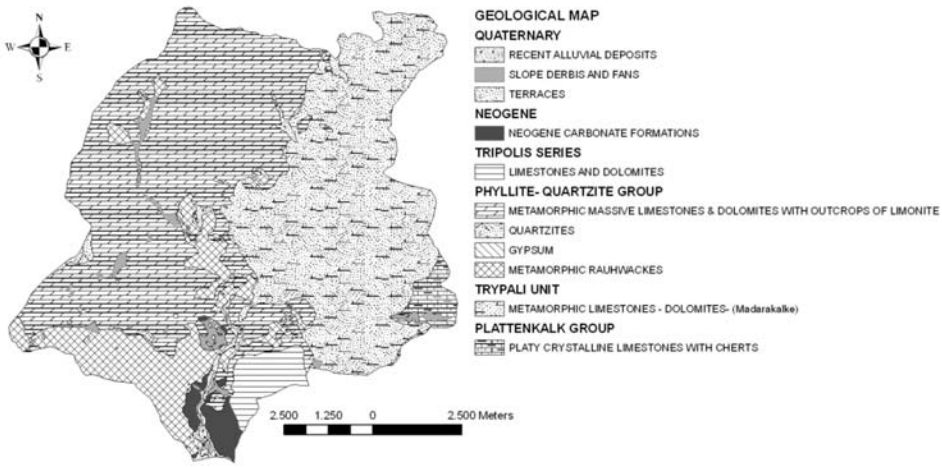

Fig. 2: Digitized geological map after Tataris et al., (1969) of Agia Eirini drainage basin.

The wider research area is part of a mega-structure, that determined the morphotectonical evolution of the region during the Neogene and the Quaternary. The visible core of this structure is the Gigilos mountain peak, on the northern part of the Samaria gorge, which is build by the older rocks of the Plattenkalk series (Manutsoglu et al, 2003). On both sides of this peak the strata dipping is changed, for the overlying formations, for the Plattenkalk group and for the rocks of the overthrusted Trypali unit, while maintaining a similar direction of NNE-SSW. On the NW side of the Samaria gorge, the overlying formations have undergone intense tectonic movement, forming a tectonic breccia of considerable thickness. This mega-structure dips towards NE.

As a result of this dipping, at the SW part of the Samaria Gorge the formations of the underlying Plattenkalk unit are not present; instead the metamorphic carbonate rocks of the Trypali unit appear. The contact is tectonic and is characterized by the existence of tectonic breccia, which locally exceeds 2 m thickness. The nappe thickness at this location is no more than 50 m, but to the west it is more than 200 m. The Agia Eirini gorge evolved in this fractured metamorphic carbonate sequence of large thickness. In the I.G.M.E. geological map (Tataris et al., 1969), the gorge is shown to evolve entirely in the Trypali unit metamorphic rocks. However, field work revealed that also metamorphic rocks of the Plattenkalk group appear in the gorge, which are not shown in the map, probably due to its scale (1:50000). The appearance of the tectonically lower unit is of significant importance for the explanation of the formation of the gorge, which simply evolved along a fault zone. To exhibit all these data, a three dimensional morphotectonical - geological model has been constructed (Manutsoglu et al., 1999).

3. Data and results

3.1 Data

The basic aim of this work was the assessment of the vulnerability degree of different lithological formations in the drainage basin of Agia Eirini gorge. The gorge comprises the Quaternary and Neogene formations, the carbonate rocks of the Tripolis series, the Plattenkalk Group, the rock of the Trypali unit and the Phyllite –Quartzite group (Fig 2).

For the attainment of this aim, the following data were used:

- geological map, 1:50.000 scale (Alikianos sheet), by the Institute of Geology and Mineral Exploration (I.G.M.E.),
- topographical map, 1:50.000 scale (Vatolakkos sheet), by the Hellenic Military Geographical Service (H.M.G.S.),
- digital map of the Cretan region with 20 -meter elevation contours,
- land use map, 1:100.000 scale of the European program CORINE land cover,
- data and records acquired from field work conducted in the study area.

For the storage, processing and analysis of the primary data, the ArcGis program of ESRI was used. With this software we set up a database for the study area. Besides primary data, the database includes secondary data as well, which were derived by the analysis and processing of the raw data and by all studies conducted in the area. The secondary data include the digitized geological map (which is supplemented with details from field work), the digitized river network, the digital terrain model, the map of morphological gradients, maps of the hydrographic frequency and density etc.

The vulnerability degree of the geological formations in the basin of Agia Eirini resulted from a combination of four variables. These variables are related with the weathering impact on formations either directly or indirectly and they can be displayed spatially (Marinos et al. 1998, Alexouli – Livaditi et al. 2002, Lycoudi & Scarpeli 2006), with the production of the following thematic maps:

- map of geological formations susceptible to weathering,
- map of morphological inclinations,
- map of hydrographic texture,
- land use map protecting against the loss of disintegrated material.

The combination of the above maps (based on their impact to weathering) produced maps dis-

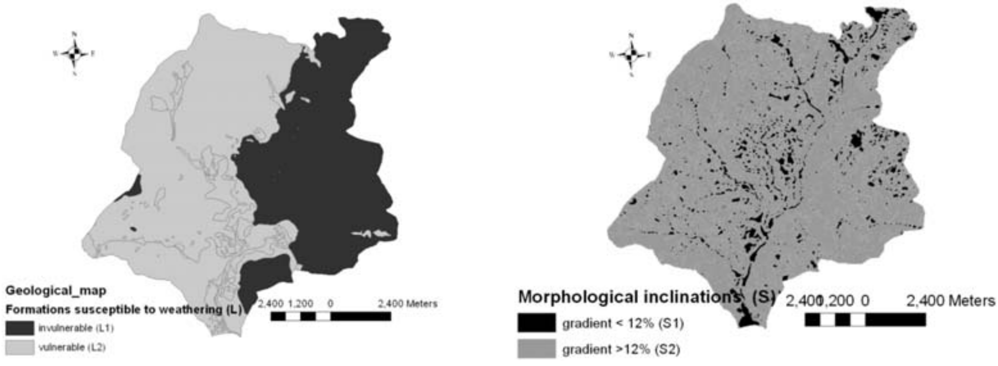

Fig. 3: a) Map of geological formations susceptible to weathering (L). b) Map of morphological inclinations (S).

playing the vulnerability degree of the formations and, thus, the risk of material loss. With this method we constructed two applications: with and without the vegetation cover factor.

3.2 Data analysis and results

Based on geological, hydrogeological and hydrolithological (permeability) information, the digitized geological map was converted into the map of geological formations susceptible to weathering (L) (Fig 3a). In especial this conversion was based on the stone composition, the degree of transformation, and qualitative data from field work related to the weathering mantle observed.

The formations were classified into two categories. The first one comprises formations rather invulnerable with little disintegrated mantle thickness (L1). The second one contains the vulnerable formations with thick disintegrated mantle (L2). The first group (L1) comprised the carbonate rocks of the Tripolis series, the Plattenkalk Group, the rock of the Trypali unit and quartzite parts of the group of Phyllite -Quartzite. Group (L2) consisted of almost all the Phyllite -Quartzite series and the Quaternary and Neogene formations.

From the digitized topographic map of the region we created the digital terrain model (DTM) by using the ArcGis software. With further processing the DTM model, the morphological inclination map was produced. This map was classified depending on the gradient of slopes and two categories were distinguished The first category (S1) includes areas with slopes of less than 12% and the second group (S2) areas with slope greater than 12% (Fig 3b).

The watershed and the drainage network of the study area were digitized and sorted according to Strahler (1964) classification. The drainage network and, therefore the basin of the gorge of Agia Eirini are of the fifth class. Then, the lower order basins of the 4th and the 3rd class were digitized and the values of the hydrological frequency and density were calculated for all the basins. The drainage density (Du) of an order u drainage network is "the ratio of the total length of all branches of the river network of a u order basin to the area of this basin" (Horton 1945). Drainage frequency (Fu) of an order u drainage network is "the ratio of the total number of branches of an order u basin to the area of this basin" (Horton 1945). In a river network, the tex-

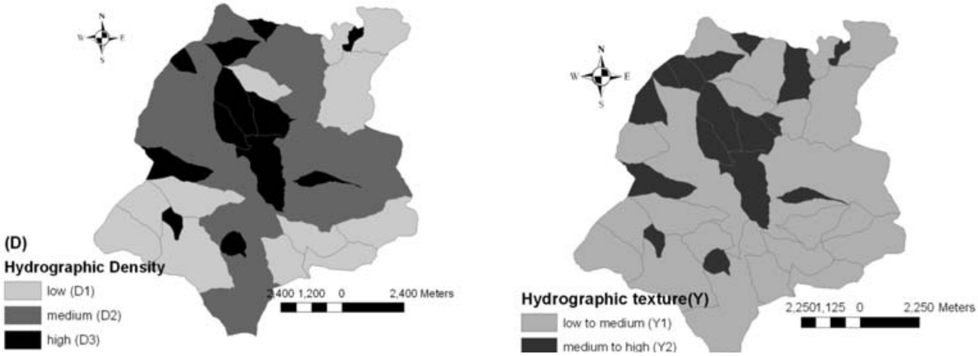

Fig. 4: a) Map of hydrographic density (D). b) Map of hydrographic texture(Y).

Table 1. Categorisation of vulnerability factors

1) Geological formations susceptible to weathering (L)	invulnerable L1: limestones, dolomites, quartzites etc.	vulnerable L2: contemporary silting, colluvial deposits, phyllites etc.	
2) Morphological inclinations (S)	S1: $<12\%$	S2: $>12\%$	
3) Hydrographic texture (Y)	Low to medium Y1: Combination of F1, F2 and D1, D2	Medium to high Y2: Combination of F2, F3 and D2, D3	
3a) Hydrographic frequency (F)	low F1: $F \leq 6,81$	medium F2: $6,81 < F \leq 9,32$	high F3: $9,32 < F$
3b) Hydrographic density (D)	low D1: $D \leq 2,82$	medium D2: $2,82 < D \leq 3,44$	high D3: $3,44 < D$
4) Land use/vegetation cover (C)	C1: sparse shrubs, grasslands and areas with little or no vegetation	C2: olives and agricultural areas	C3: forests

ture is determined by the growth sectors of the drainage basin and depends on the parameters of the drainage density and of frequency. The drainage basin area of the gorge is 100 km^2.

We created the map of hydrographic texture from the maps of hydrographic frequency (F) and hydrographic density (D) (Fig. 4a). According to Table 1, the study area was divided into three categories of hydrographic density and frequency: high, medium and low, D1, D2, D3 and F1, F2, F3, respectively. The combination of these categories provided the “hydrographic texture map”, which comprised two categories of areas: a) with low to moderate texture (Y1) and b) with moderate to high texture (Y2) (Fig. 4b).

The first category includes areas with medium and low values of frequency and density and the second category areas with high and medium values of frequency and density.

Table 2. Classification of vulnerability provided by the combination of the first three thematic maps (without the vegetation cover factor)

VULNERABILITY WITHOUT THE VEGETATION COVER FACTOR				
Vulnerability	(Low) T1	(Low to medium) T2	(Medium to high) T3	(Very high) T4
	L1,S1,Y1	L1,S1,Y2 & L1,S2,Y1 & L2,S1,Y1	L1,S2,Y2 &L2,S1,Y2 & L2,S2,Y1	L2,S2,Y2
Area (km^2)	4,21	36,49	44,71	14,59
Percentage (%)	4,21	36,49	44,71	14,59

Taking into account the three final maps of the first three thematic sections, described above,- map of geological formations susceptible to weathering (L), map of morphological inclinations (S) and map of hydrographic texture (Y)- a new map was produced. This was the map of formations vulnerability and risk of material loss (T), based on lithological and geomorphological criteria but without taking into account the factor of vegetation cover (Fig. 5a). The combination of those three thematic maps, led to determination of the study area into four zones of vulnerability (table 2).

Extending the investigation of the influence of various factors on the vulnerability of the formations and creating a simulation model of vulnerability led to taking another factor into consideration. The vegetation cover factor was categorized according to “Corine” land use map and field observations. Three groups of vegetation cover were distinguished: a) sparse shrubs, natural grasslands and areas with little or no vegetation (C1), b) olive groves and other agricultural areas (C2) and, c) forests (C3) (Alexouli-Livaditi & Livaditis 1997, Alexouli-Livaditi et al. 2002).

The protection offered by vegetation, is clearly dependent on the type of vegetation. The greatest protection is provided by thick forests and dense bushes. Less protection is offered by sparse woods and various crops. Areas with no vegetation are totally unprotected (Kotoulas 1985).

Combining information of the vulnerability and vegetation cover maps produced the “vulnerability map of the lithological formations and of risk of material loss considering the vegetation factor“ (ST). (Fig. 5b), It also produced the determination of the research area into four zones of vulnerability (table 3).

Table 3. Classification of vulnerability provided by combination of the four thematic maps (with the vegetation cover factor).

VULNERABILITY WITH THE VEGETATION COVER FACTOR				
Vulnerability	(Low) ST1	(Low to medium) ST2	(Medium to high) ST3	(Very high) ST4
	Combination of T1 & C1,C2,C3 T2 & C3	Combination of T2 & C1,C2 T3 & C3	Combination of T3 &C1,C2 T4 & C3	Combination of T4&C1,C2
Area (km^2)	15,96	27,95	41,85	14,24
Percentage (%)	15,96	27,95	41,85	14,24

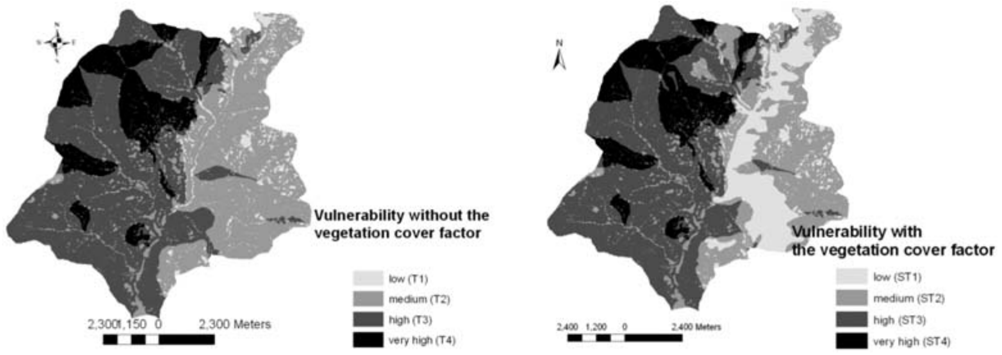

Fig. 5: Map of vulnerability without the vegetation cover factor. b) Map of vulnerability with the vegetation cover factor

4. Conclusions

Sustainable management of protected areas requires good knowledge of the entire system and effective tools. Setting up a GIS with the possibility of spatial and qualitative assessment of the potential loss of disintegrated material is a powerful tool essential for the management and protection of natural ecosystem of Agia Eirini gorge.

In this work the appropriate combination of a series of maps produced thematic maps presenting the vulnerability of the basin formations of the gorge of Agia Eirini and the risk of losing the disintegrated material. The results of this process can be a guide to monitoring and sustainable environmental management of the basin of the gorge of Agia Eirini.

The existence of this information in a GIS has a lot of advantages. Besides the possibility of future adjustments and all the advantages of a digital database, the proposed method of spatial estimation of material loss could be used to predict the impact of future changes (e.g. land use changes) or in disaster scenarios (e.g. destruction of plant cover due to fire) and define the effects of those changes on the natural environment.

Identifying high risk positions gives the opportunity to take protecting measures and prevent the environmental impact Moreover this method is necessary for the application of the Water Framework Directive 2000/60 and for the spatial planning of land use.

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