Environmental and Human Risk Assessment of the Prehistoric and Historic Archaeological Sites of Western Crete (Greece) with the Use of GIS, Remote Sensing, Fuzzy Logic and Neural Networks

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Abstract. The island of Crete is an area with continuous habitation for more than 6 thousand years consisting of a variety of archaeological sites. The vulnerability of those archaeological sites is extremely high due to the changing land-use practices and various natural disasters. The use of modern technologies such as Geographical Information Systems (GIS), Remote Sensing (RS), and Global Positioning Systems is considered to provide a valuable tool for the protection of cultural heritage from human and environmental threats. Additionally, sophisticated classification methods based on fuzzy and neural networks theory contribute to a more detailed and precise mapping of the archaeological regime of the island.

Keywords: GIS, Crete, Archaeological Sites**,** Fuzzy Logic, Neural Networks.

1 Introduction

Nowadays it is well known that the conservation of the archaeological heritage is endangered by different environmental and human factors such as landfills, fires, seismicity, land use practices and urbanization [2, 18]. Thus, Geographical Information Systems (GIS) are used to combine several different factors in order to proceed to the construction of a risk assessment model. The use of GIS provides the most effective methodology for such kind of integrated analysis based mainly on spatial information [1].

2 Study Area, Data and Methodology

The study area covers the western part of the island of Crete and especially the prefectures of Chania and Rethymno. It is an area with a rich record of prehistoric and historic archaeological sites. The climate of study area is sub – humid Mediterranean with humid cold winters and rather warm summers [17].

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Initially, digitization of 1:50,000 scale topographic and geological maps of the Geographic Service of the Hellenic Army and of the Institute of Geological and Mineral Exploration were accomplished respectively. The original Digital Elevation Model (DEM) of the study area with 20m pixel size was based on SPOT satellite stereoscopic images. The geological formations of the geological maps were reclassified and all the geomorphologic attributes and details of the above maps, such as rivers, lakes, faults and modern villages were also digitized and superimposed on the particular background layers.

3 Analysis of Environmental and Human Factors in GIS Environment

The risk assessment model was separated to two different parts regarding the environmental and the human factors. Initially, each agent was analyzed separately and at the end they were combined to provide a final risk assessment model.

3.1 Environmental Factors

The main environmental factors that were used to the risk assessment model were seismic risk, erosion risk, landslide risk, and distance from the coast. These agents have been proved to cause major problems to the archaeological relics.

3.1.1 Seismic Risk of Archaeological Sites

Crete is located on the apex of the Hellenic arc and it is characterized from the often occurrence of earthquake [9-11]. Thus, the seismic activity has been selected as one

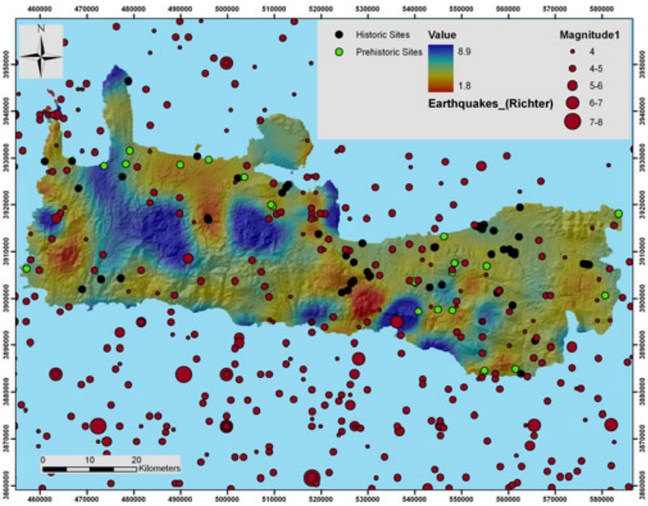

Fig. 1. Regional seismicity of Crete and application of spline interpolation method to the seismic intensity parameter

of the most crucial natural hazards that could cause severe damages to the archaeological sites of western Crete. The seismological data of the specific research were collected from the digital archives of the Aristotle University of Thessaloniki and the Geodynamic Institute of Athens. These data concerned the last century's seismic activity focusing in the wider region of Crete since May 2005. The data regarded the epicenters of earthquakes of magnitude larger than 4R and its corresponding density. The following equation was used to relate intensity with magnitude [12]: Io = a + bM, where a =1.23 and b=1.1 for the surficial earthquakes in the area of Greece.

In order to present the intensity factor through a continuous raster image the spline interpolation method was used (Fig. 1). In the end of the process, a sigmoidal membership monotonically increasing function based on fuzzy theory was applied to the final interpolated image to classify the values from 0 to 1 indicating a continuous increase from non membership to complete membership. Examining the statistics it was obvious that most of the archaeological sites fall inside a moderate earthquake risk zone.

3.1.2 Landslide Risk Assessment of Archaeological Sites

Landslides are considered to be extreme natural hazards worldwide, causing human losses and severe damages to the modern facilities [3, 6]. The specific study used the landslide model derived from the work that has been carried out during the course of the EMERIC project [5, 16]. Different environmental data such as geological data from the unified geological map of IGME, slope data derived from stereoscopic SPOT satellite images, hydrolithological data, average precipitation and a database of geological and tectonic faults were used for the construction of the final landslide risk assessment model.

The geologic regime of the study area is quite complicated. All the formations were digitized in GIS environment and the final map was simplified to 12 main geological formations. The great majority of archaeological sites was established on carbonate formations.

The average rainfall data of 65 meteorological stations of the National Meteorological Service and the Ministry of Agriculture for the period of 1991 – 2000 were obtained and recorded. Average annually rainfall maps were created through the use of interpolation methods to create final continuous raster maps. At the end 3 main categories of rainfall data were considered: 224-600mm, 600-1000mm and >1000mm of rain.

The landslide risk assessment model was based on a three different synthetic agent model. The first model was related with hydrolithology, precipitation and slope (M1) of the study area. Hydrolithology-precipitation relation was established by giving an increasing weight factor from gypsum and karst formations and relatively high to medium hydropermeability and low precipitation levels to non permeable formations with relatively low permeability and high levels of precipitation. Slope inclination-rainfall interaction was established by assigning a rising weight factor from lower inclination and low levels of precipitation to higher inclinations (>50 degrees) and high levels of precipitation. The algebraic multiplication of the two weighted surfaces provided the first category of landslide agents (M1).

The second agent was based on the relation between geology and inclination (M2) and the third agent was based on the relation between geology and distance from fault areas (M3). A low weight factor was applied to areas with low inclination. Medium to high weight factors were assigned to neogene formations and quaternary deposits with a relative average inclination (~30-70 degrees), while large weight factors were assigned for almost all formations (except carbonates and plattenkalk) belonging to high sloping areas. Regarding the third agent, buffer zones of 1000m and 500m were created around each active and non active tectonic fault correspondingly and the geologic regime of each buffer zone was weighted accordingly. All the fault buffer zones that were located within neogene and quaternary deposits, flysch and phyllites received a high weight risk factor.

The final landslide risk model was computed by using the below equation (Eq. 1).

$$Risk_{landslides} = a_1*M1+a_2*M2+a_3*M3 \ . \qquad (1)$$

All the coefficients were specified based on past landslide occurrences in the island of Crete. In the final model, the landslide risk map was classified to three main categories, from 1 to 3, indicating the increasing landslide susceptibility (Fig. 2). At the final results, 76 sites fall within the moderate landslide risk zone and only 5 historic and 4 prehistoric sites fall inside high risk zone.

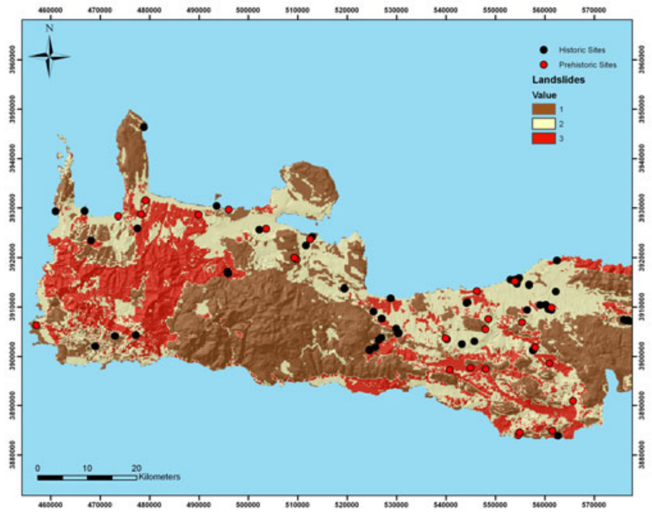

Fig. 2. Landslide risk assessment model

3.1.3 Distance of Archaeological Sites from Coast

The archaeological sites that are established along the coastlines environments are always threatened by shoreline erosion, sea wave storms, tsunamis and sea level rise [14]. In the case of the western Crete many different types of archaeological relics are close to the coast. In order to search the regime for the risk of the coastal environment, a buffer zone of 500m with a risk value of 1 was created around the coastline of western Crete with direction to the inlands (Fig. 3). Examining the statistics, 17 archaeological sites were found within this buffer zone.

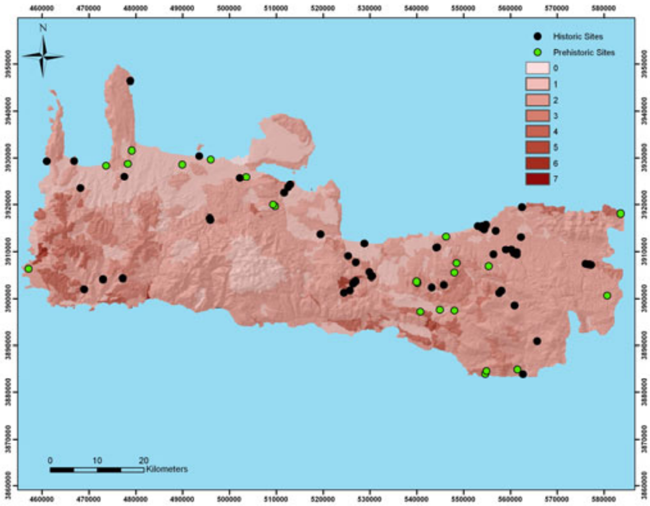

Fig. 3. Erosion risk assessment model

3.1.4 Affection of Soil Erosion to Archaeological Sites

Regarding soil erosion, the specific phenomenon should never be ignored because of its importance in affecting landscape sustainability [6, 19, 20]. However, at Crete terracing has contributed from the ancient times to decrease soil erosion rates.

Regarding the data for the specific study, all were digitized in GIS environment and the final maps were reclassified to 7 erosion rate classes (Fig. 4). The vast

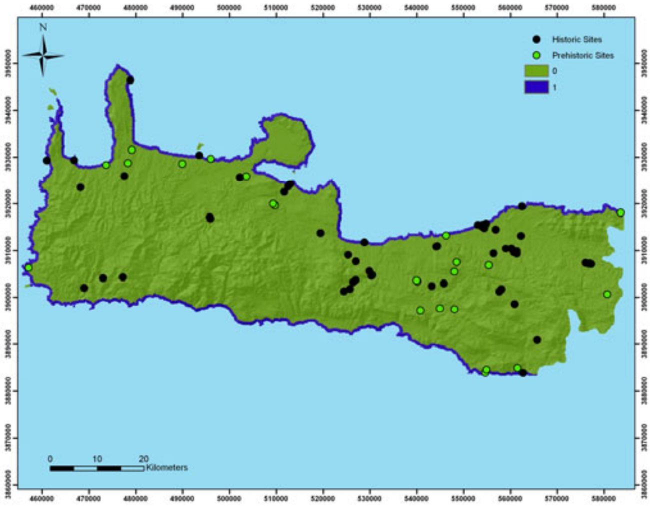

Fig. 4. Coastline risk assessment model

majority of both historic and prehistoric sites are established in low erosion risk areas. At the final raster archive, a fuzzy logic algorithm was applied to normalize the values from 0 to 1.

3.2 Human Factors

Considering the treat of cultural heritage, various parameters can be attributed to the human driven agents. The continuously expanding cities and villages, the industrialization and development works, the agricultural fires, the land use and cultivation practices, the proximity to landfills and other waste disposal areas and air pollution can be attributed as main human risk factors. In the specific model, four agents were considered, namely agricultural fires, proximity to landfills and urban and tourist centers and land use.

3.2.1 Agricultural Fires Risk Assessment

The estimation of agricultural fires risk assessment was based on the results of EMERIC project [15, 16]. Satellite imagery was used (9 Landsat-5 thematic mapper and Landsat-7 enhanced thematic mapper images period of 1985to 2003) to provide information regarding the changing vegetation patterns for the last 20 years. The images were classified to highlight changing patterns of land use, followed by an object-oriented classification to produce a digital image of vegetation types based on more than 1000 ground-control points.

The final fire risk assessment model was based on a classification of risk based on the evaluation of certain parameters such as the vegetation distribution (based on the reflectance of Landsat TM5 images at the NIR (0,76 - 0,90μm), the vegetation type (based on the object-oriented classification of the Landsat images), the fire potentiality of the major types of vegetation, the historical registries of fires (area extent and frequency) and the Digital Elevation Model (DEM). All these parameters were applied on specific training sites and three categories (low, moderate and high) of fire risk assessment were derived. These categories were further expanded to the rest of the satellite image through supervised classification algorithms. The final fire risk model was derived for the year 2010 based on the changes of the land use practices, the logarithmic increase of population, the percentages of moisture and temperature and the altitude and slope of the terrain. Finally, about 50 historic and 16 prehistoric sites were found to be located within regions with a high fire risk (Fig. 5a).

3.2.1 Proximity of Archaeological Sites to Landfills

It is well known, that landfills are seriously affecting the degradation of the landscape. However, except the national or municipal controlled landfill areas, there are also a number of illegally operating landfills that endanger the archaeological reserves and parks.

After an extensive GPS survey 55 legal or illegal landfills were registered in the prefectures of Chania and Rethymno. According to the Greek legislation, a landfill site should not be located within a distance of 500m from an archaeological site. The final landfill impact zone was created by applying a buffer zone of 500m around each landfill. At the final results, only 3 archaeological sites were found inside the specific buffer zone (Fig. 5b).

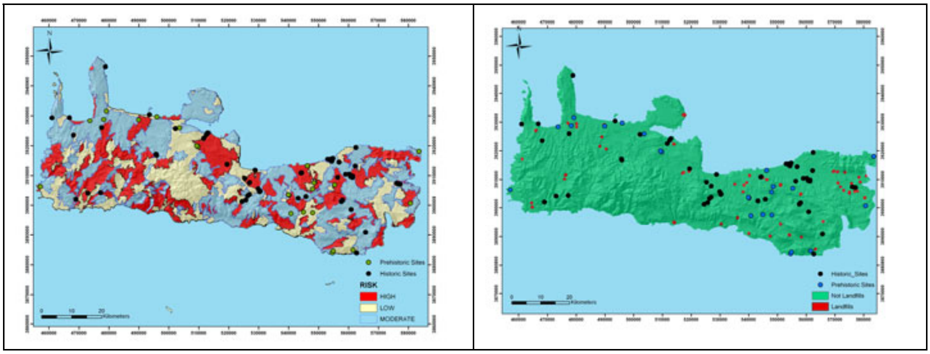

Fig. 5. (a). Fire risk assessment model. (b). Landfills risk assessment model.

3.2.3 Urbanization and Land Use Practices

During the last centuries, urbanization and agricultural cultivation seem to have an important impact on the preservation of the archaeological sites. A buffer zone of 1500m was created around towns and villages to identify the areas under urbanization pressure. About 19 sites were found to fall within these regions (Fig. 6a).

The land cover regime of the study area was examined through the use of the Corine Land Cover (CLC) database. The cartographic layers of CORINE were re-projected to the Greek Geodetic Reference System (GGRS'87) and the land use categories were reclassified to 3 levels of low, moderate and high risk. Most of the registered archaeological sites were found within the moderate risk cultivated lands (Fig. 6b).

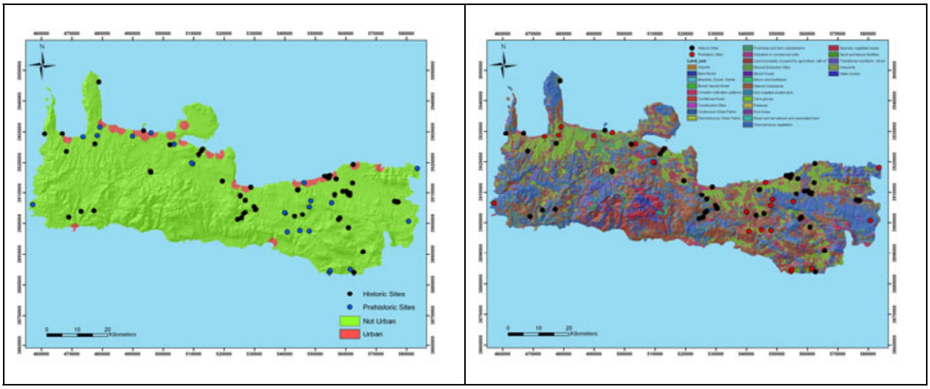

Fig. 6. (a) Urbanization risk assessment model. (b) Corine land use classification scheme.

4 Application of Fuzzy and Neural Network Algorithms to the Final Maps

After having applied a specific rating to the subcategories of each agent, the weights of significance of the variables were specified based on the statistical analysis of the risk agents in terms of the location of the archaeological sites. The environmental parameters constructed the first category including seismic activity (Se), erosion (Er), landslides (Ls) and distance from the coastline (Co), while the second category included agricultural fires (Fi), proximity to landfills (Lf), land use practices (Lp) and urban pressure (Ur). The intermediate steps involved the construction of maps (Fig. 8a and Fig. 8b) presenting the above mentioned risks, by summing up through the use of Boolean algebra the product of each category with the corresponding weight of significance (Eq. 2).

$$\begin{gathered}\text{Environmental Model} = 0.3{*}Se+0.2{*}Er+0.4{*}Ls+0.1{*}Co\,. \\ \text{Human Model}=0.3{*}Fi+0.2{*}Lf+0.4{*}Lp+0.1{*}Ur\,.\end{gathered} \tag{2}$$

The final risk assessment model was computed by the sum of the environmental and anthropogenic risk maps. However, two models were created, one calculating an equal participation of the agents (50 – 50%).

In the final stage, a neural network algorithm was applied to all risk maps to provide a finer tuning of the classification. Artificial neural networks are non linear mapping structures that are mainly based on the structure of human brain [8]. A major advantage of the neural networks is that they are independent of the statistical distribution of the data used [13]. For this study, a neural network that is based on ART

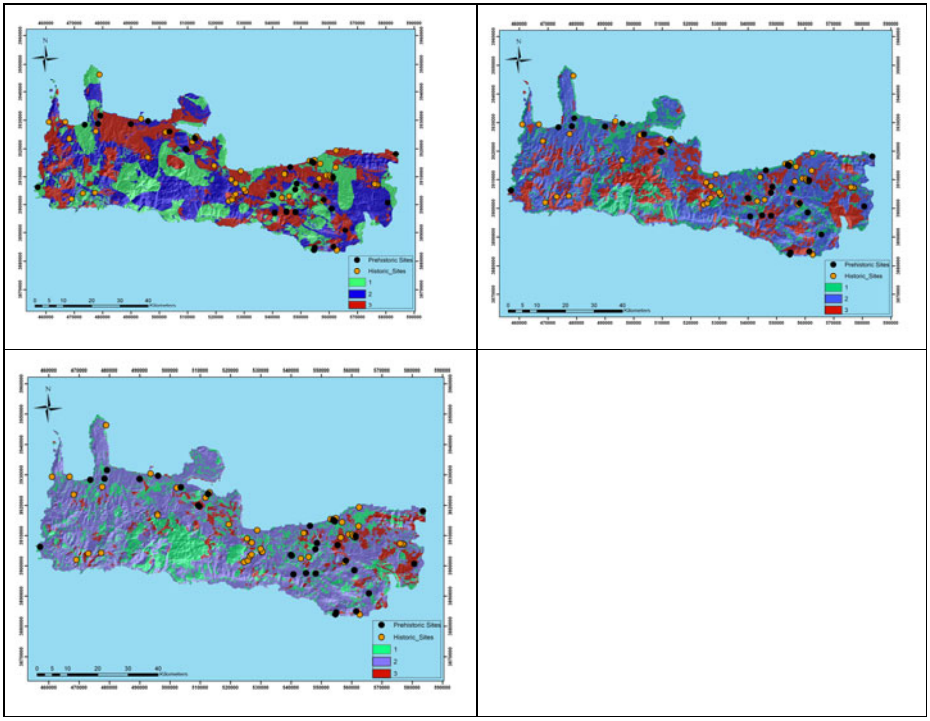

Fig. 7. (a) Environmental risk assessment model. (b) Anthropogenic risk assessment model. (c) Final risk assessment model.

Table 1. Statistical Results of the Risk Assessment of the Archaeological Sites of West Crete after the application of Neural Networks Classification Method

	Number of Prehistoric Sites	Number of Historic Sites	Sum of Sites	Risk Area (km^2)	Percent of Risk Area (%)
Environmental (Env)					
High	10	24	34	1034.5	27
Moderate	9	20	29	1482.7	39
Low	15	38	53	1296.3	34
Anthropogenic (Anthr)					
High	9	12	21	929.4	24
Moderate	11	30	41	1890.7	50
Low	14	40	54	991.6	26
0.5*(Env) + 0.5*(Anthr)					
High	11	20	31	756.1	20
Moderate	9	31	40	1647.8	43
Low	14	31	45	1407.8	37

architecture (Adaptive Resonance Theory) named fuzzy ART&ARTMAP neural network was used [9, 21]. An unsupervised fuzzy ART&ARTMAP method was applied so as the final network to be composed from 2 different layers: The input layer (F1) that receives the input data and the recognition layer (F2) that stores the final classes (clusters). The number of F2 neurons is automatically determined so as the F2 layer can begin with few layers and can grow in greater number during the learning procedures [4].

After applying several different vigilance parameters to each image, ten different classes were produced. The first 4 classes (0-4) were categorized to low risk rate, the three next (5-7) to moderate risk rate and the final 3 (8-10) to high risk rate (Fig. 7a Fig. 7b, Fig. 7c). The final results of the classification regarding the risk areas and their relationship to archaeological sites are demonstrated in Table 1.

5 Conclusions

This study brought out the fact that human and environmental factors can contribute with equal or different percentage to the degradation of archaeological monuments. Human factors such as agricultural fires and urbanization expansion may contribute to the degradation of the cultural landscape. On the other hand environmental factors such as earthquakes and landslides can provoke violent and severe damages to the sites. Regarding the final results, the environmental risk model recorded most of the high level risk areas to be located mainly in the plain regions of western Crete. However, there was not any clear demarcation of the areas with high level of human driven risk.

The results of this study can be used as a road map for taking specific actions regarding the protection of the archaeological monuments in the island of Crete. The application of fuzzy ART&ARTMAP algorithm proved to be really efficient, making the final classified results more unbiased for archaeological interpretation.

Additionally, it is really important to mention that a high percent (more than 50%) of the archaeological sites are established to moderate high risk areas. The GIS module used in this study provides the opportunity to the researchers to enter flexible more and different parameters to the final model.

Acknowledgements

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