CRM & Archaeological Research using Remote Sensing and GIS: Zhouyuan (China) & Lasithi (Greece)

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Abstract. Zhouyuan, the ancient capital of China (B.C1100 to B.C.700), is located at the center of Shaanxi province, covered by farmlands and some modern villages. The continuing archaeological investigations discovered some palace foundations, storage pits and some small tombs, while recent efforts have been focused on locating the foundations of the city walls and the royal tombs. Satellite remote sensing (Landsat TM imagery), aerial photographs and GIS techniques were employed by archaeological research for detection and photogrammetry. Aerial images were used for creating orthomaps, containing information on topography, rivers, roads, modern villages, a.o. to be used as basic background layers for mapping the archaeological sites of the region. Landsat TM images were georeferenced to the orthographic aerial image and combined, they resulted in an image of high ground resolution and wide spectral resolution to be used for interpretation purposes. The above were merged to a GIS, together with an archaeological database containing general information, mainly data and finds of the site, for further analysis.

Lasithi (E. Crete) is one of the less-developed and remote districts of the E.U. and at the same time one of the archaeologically most investigated areas in Greece, containing a number of sites from the Neolithic era to the most recent historical period. After a detailed mapping of more than 900 ancient sites (Neolithic –Roman period), research was concentrated on the extraction of the spectral signatures of the sites based on satellite imagery and the cultural resources management of the area. Information regarding the geomorphological and geological attributes of the sites, seismic activity, fires, and climatic conditions were merged into a GIS together with other archaeological information resulting to a definition of risk areas having a variable index of conservation due to the environmetal variables.

The above research projects fall within a collaborative framework of research which studies the use of satellite remote sensing and GIS in archaeological research and Cultural Resources Management in semi-arid regions with desertification phenomena, which in turn have direct consequences for the conservation of ancient monuments.

Key words: Remote Sensing, GIS, CRM, China, Greece.

1 The Zhouyuan Site. An Introduction

Zhouyuan site is located on the western part of Shaanxi province, China. The site is limited by Qi mountain in the north and the Wei river in the south, while the Qi river is running through the site. Under the threat by its northern neighbors, namely the Rong and Di national groups, Gugong Tanfu led the Zhou people from their hometown Bin to the wider region of Zhouyuan. Before king Wen moved his capital to Feng in the late period of his reign, Zhouyuan remained the political center of the Zhou people. During the western Zhou dynasty (11-7B.C), Zhouyuan kept a special political position as the holy capital.

It is in Zhouyuan that the Zhou's political power spread quickly and developed into a main adversary of Shang dynasty during the reign of three generations of kings, namely Gugong, Jili, King Wen and the defeated Shang dynasty.

According to the ancient documentary, hanshu, some bronzes were discovered in Zhouyuan area in 58 B.C. Since then, Chinese researchers have paid attention to the Zhouyuan area, where bronzes were frequently discovered. Archaeological excavations in Zhouyuan site were initiated in the 1950's. Several decades of surface surveys and excavations have identified the extent of the site and the distribution of main vestiges of Zhou culture. Zhouyuan site covers roughly 56 sq km, 7.5 km in length and 7.5km in width.

1.1. Main Pre-Zhou period Sites

1. Pre-Zhou cultural remains are mainly situated in the western part of site, such as Wangjiazui Village, Hejia Village and Licun village. Cultural remains include relics of houses, pits, and a cemetery attributed to the culture of king Gugong, Jili period.

2. Liujia Cemetery includes 20 tombs dated to the late period of Shang dynasty.

Most scholars regard them asdated to the Qiangrong culture.

The above pre-Zhou period remains are the most important material, used to study the transformation of the Zhou culture.

1.2. Building Remains

In the Zhouyuan site there are a lot of group foundations of superior western dynasty buildings, such as Zhuangbei, Shaochen, Qizhen, Yuntang, Qijia, Fengchu, etc. These building remains include rammed earth platforms, foundations of pillars, stone aprons, stone roads, cover tiles, bed tiles, and other structural characteristics. These buildings probably belong to the royal or high rank nobles.

1. Fengchu complex of buildings: Group A

The foundation of group A consists of a rammed earth platform, 45.5m in length, 32.5m in width, with a total area coverage of 1469m^2, including a hall, houses, a forward yard, back yards, corridors and guard houses. The two pits, in which

the important Zhou oracle-bone inscriptions have been found, are located in the second house of the western section.

2. Yuntang complex of buildings

A group of foundations of buildings in late western Zhou was excavated in 1999-2000. Foundations F1, F2, F3, F8, F5, with high rammed earth platforms and a circle wall, integrate into a group of closed, symmetrical buildings. Among them, the outline of F1 looks like a "V"-shape, 22m in length and 16.5-13.1 in width. A hall, surrounded by some houses, is located on the center of the platform. There are steps at the different sides of the platform (one step at the east, west and north fringes and two steps at the south). F2 and F3 are located SE and SW of F1 correspondingly, having a length of 11.6m and a width of 8.5m. A janitor's room is located in the middle of the southern rim of the forward yard. A "U"-shaped stone road connects the main platform with the gate and janitor's room in the yard. F5 is located west of F1. The group of buildings suggests that it is probably related to an ancient temple.

1.3. Cemeteries

Some cemeteries are scattered in Licun, Qijia, Yuntang, Zhuangbei and Huangdui villages. They include tombs of various sizes (large, medium and small size tombs can be found in all cemeteries). Groups of bronze ritual vessels, weaponry and precious jades have been found in some large size tombs, while only pottery has been found in small size tombs.

1.4. Bronze hoards

In Zhouyuan site, roughly 70 hoards were discovered, including more than 600 bronze vessels, dating from early to late period of western Zhou dynasty. All the hoards can be dated back to the late period of western Zhou. The appearance of the bronze hoards can be related to the escape of bronze-owners during the invasion of Quanrong nation from northwestern and the resulting collapse of western Zhou dynasty.

These bronze vessels were made exquisitely and they are well preserved. They include a lot of important inscriptions that constitute the main documentary of western Zhou dynasty, such as the inscription of Shiqiang plate, recording the main political affairs of 6 kings of the early western Zhou dynasty and the history of 7 generations of the Weishi family, the inscription of Wei Ding (a kind of cooking vessel), recording a case of land exchange and some law rules of western Zhou dynasty, as well as the inscription of Donggui (a kind of bowl), recording the war between Zhou and peripheral nations, such as Huaiyi, Yanrong.

2 The Study of RS and GIS in Zhouyuan Site, China

In the study of RS and GIS in the Zhouyuan site, satellite imagery (TM images were collected in summer and autumn) and aerial photographs (Fig. 1) were employed for archaeological remains detection and photogrammetry. In the Zhouyuan site, all the building foundations and tombs are made of rammed earth (Fig.2). The rammed earth is very dense and has smaller moisture content than the rest of the soil. On the other hand, in the early and middle October, almost all the crops on the Zhouyuan site have been harvested, the ground almost been exposed, and thus the near and middle infrared Landsat TM images (bands 4, 5, 7) could distinguish the tiny differences in humidity of the surface layers of the soil. Similarly, combination of bands 7, 5 and 4 to a false color image (RGB) was used for image enhancement. A number of linear features of high reflectivity were identified in the combined TM images, especially those taken in the autumn. Many of the brighter linear features found on the autumn TM images were produced by archaeological remains (rammed earth structures of building foundations or tombs), since the rammed earth is drier than the rest of the soil (lower absorption of the infrared bands).

Fig. 1. Black-and-white aerial photography of the Zhouyuan site

Fig. 2. Excavated palace foundations, made of rammed earth.

GPS geodetic stations were used to obtain high accuracy GCPs (Ground Control Points), which were ultimately used to create photogrammetrically a new map of the Zhouyuan region. The GCPs' coordinates were used together with stereo aerial photographs to create a 3-dimensional imagery model of the site. The different topographic layers (elevation contours, rivers, roads, modern villages and orthographic aerial images) were

imported to a GIS platform to create an interactive Zhouyuan archaeological information system. Finally, TM images were also georeferenced and resampled in order to be fused with the orthographic aerial image (Fig. 3). In this way, the TM images and the orthographic aerial images were combined together to form an image of high ground resolution and wide spectral resolution, which was used in the interpretation of the surface characteristics of the landscape. At the end, all the geographically referenced information and data were used as an input to a GIS system for further analysis.

Fig. 3. Aerial photography, combined with TM imagery.

Fig. 4. The relationship of two palace foundations. The east one has been destroyed very seriously.

3 Zhouyuan site. Conclusion

Satellite remote sensing and photogrammetric techniques were able to identify and locate a number of cultural features in the Zhouyuan site, including some important palace foundations, two of which were excavated (Fig. 4) bringing to light important archaeological features. Photogrammetric techniques were also used to merge the low-resolution Landsat TM images with higher resolution orthophotos, enhancing the analysis of the landscape of the region.

Further analysis is under progress, including the spatial analysis of the distribution of the tombs, palace foundations, bronze hoards etc., in an effort to infer the locations of other remains which will contribute to building a more synthetic image of the cultural landscape of the Zhouyuan site.

4 Lasithi District, E. Crete, Greece. An Introduction.

The recent mapping of the archaeological sites of Lasithi district (almost 1000 sites dated mainly to the Neolithic-Roman period) and the construction of a digital archaeological map (Sarris, *et al* 2002) introduced a new input for the management of cultural resources in the region. The need for the development of a CRM model is of critical value, since Lasithi is one of the less-developed and remote districts of the E.U. and at the same time one of the most archaeologically investigated areas in Greece.

Taking into account factors such as the seismic nature of the region, the fluctuations of the climate, the proximity to geological features, the impact of modern interventions and the geomorphological and geological attributes of the sites, a risk-area definition model can be achieved with respect to the type of sites threatened within their environmental and landscape context. In this way, a territorial information system can be constructed for monitoring the above variables, so that it can operate as an apparatus for cultural resources management, suggesting modes of preserving cultural monuments.

Natural hazards, from storms and earthquakes to fires and flooding, as well as the changing landscape due to agricultural activities or construction works, are damaging the cultural sites and their monuments. The definition of the parameters that influence the preservation of monuments is a key factor to cultural resources management (CRM), with wide range of effects to all sectors of the society.

5 Analysis of Cultural and Environmental variables in the Lasithi District.

5.1. Archaeological Database.

The archaeological database contains 972 records, the largest percentage of which (67.59%) are sites dated to the Minoan period. 318 out of the total of 656 Minoan sites are dated to the Late Minoan period. Roman period sites come 2nd in number (15.43% of the total number of sites). No Palaeolithic or Mesolithic sites are known at the Lasithi district.

The abovementioned sites were divided in 9 typological categories: habitation sites (29.63%), sites of unknown typology (26.13% - derived mainly from survey publications, where there is no detailed description of the typology), burial sites (20.16%), isolated buildings (11.21%), religious sites (10.80%), fortifications (7.20%), caves (7%), other categories (5.45% - containing sherds' concentrations, cisterns, roads, etc.) and production sites (4.73%). The main purpose of the above classification scheme was to specify a different conservation factor (or risk factor) for each type of site.

Although 320 out of the 972 archaeological sites were visited during fieldwork activities, site verification was achieved in just 209 of them. Thirty of these sites are fenced, 89 are well preserved, 96 are poorly preserved and 46 have been found destroyed (Fig. 5).

182 out of 972 sites have resulted from excavation research: systematic excavation for 69 sites, rescue excavation for 18 sites and trial excavation for 12 sites. For 83 sites the excavation method is not mentioned in the corresponding publications. 104 of the sites were excavated by Greek excavators, 49 by foreign excavators and 29 by both. The largest number of the excavated sites belongs to the Minoan period, following by the Protogeometric – Geometric sites.

667 sites have been located by surface survey techniques: 347 by extensive surveys, 304 by intensive surveys and 16 by both methods. Most of the sites located by surface surveyes are dated to the Minoan period, following by those belonging to the Byzantine period.

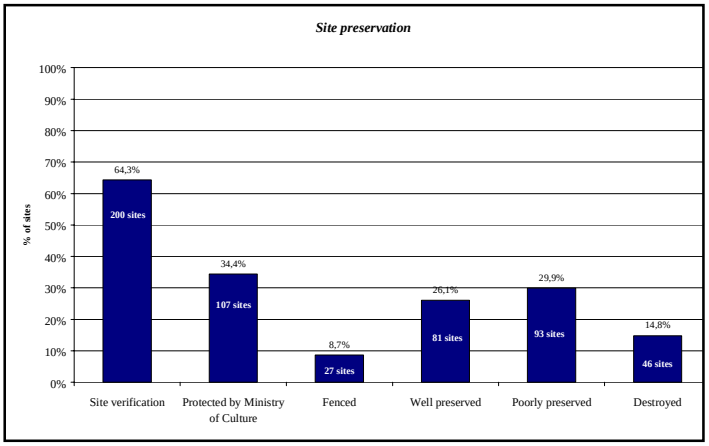

Fig. 5. Histogram indicating site verification and site preservation in the Lasithi district.

5.2. Geology & Physiography of sites.

The digitization of the geological maps, landuse maps and landcapability maps contributed to the further correlation of the archaeological sites with their geomorphological context. The following statistical analyses concern 717 out of 972 sites, since those were the only ones with known coordinates, to be spatially joined with the digitized geomorphological maps.

The largest quantity of sites (37.24%) is located on tertiary deposits, followed by a percentage of 34.30% of sites located on hard limestone. 13.11% of the sites are located on schist, 7.81% on alluvium, 4.32% on mixed flysch, 1.39% on deposition cones and 1.39% on limestone colluviums, 0.42% on peridotites and 0.28% of the sites are located on granites.

The largest percentage of sites (61.51%) is located on rounded summits, followed by 21.20% located on lower slopes, 7.39% on middle slopes, 5.30% in open valleys, 3.21% in closed valleys and 1.39% in cliffs or escarpments (Fig. 6). Most of the sites located on rounded summits are religious sites. A lot of isolated buildings and production sites can also be found in such locations. All sorts of typological categories are found on lower slopes. Fortifications and habitation sites have almost the same percentage of presence on middle slopes. No production sites are found on this type of physiography. In contrast, most of production sites are found to be located in open valleys.

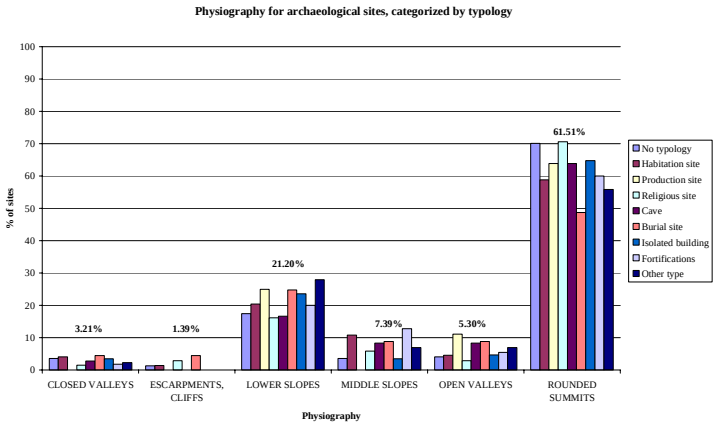

Fig. 6. Histogram indicating the landscape physiography of the archaeological sites of the Lasithi district.

The largest percentage (78.80%) of sites belongs to the "none and moderate" erosion category. This is in agreement with the slope classification, as most of the sites are located on "gentle" (59.49%) or "gentle and moderate" (25.24%) slopes. Less than 7% of the sites are located on steeper slopes.

The high percentage (34.73%) of sites found in agricultural areas suggests an increased risk for their preservation status. Out of a total of 146 sites visited, at least 25, found destroyed and another 41 poorly preserved, belong to such areas.

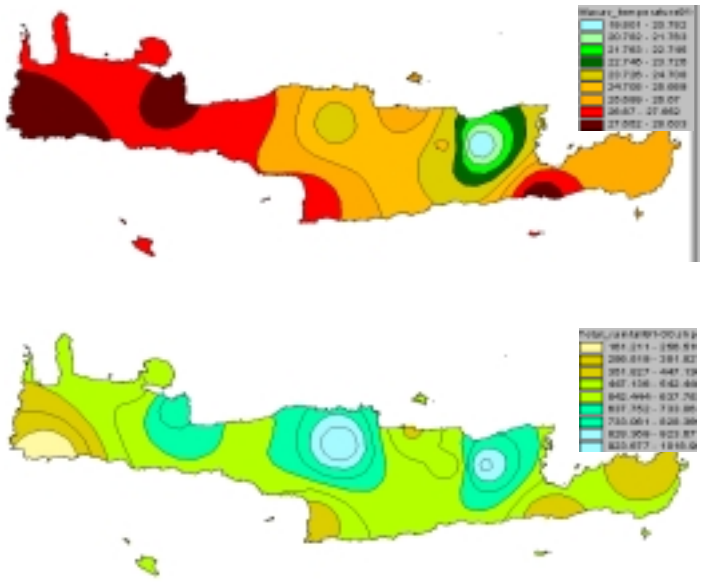

Fig. 7. Maximum Average Temperature (1991-2000) (above) and Total Rainfall (1991-2000) (below).

5.3. Climatic Data.

The climatic data derived from the National Meteorological Service of Greece. These data refered to the mean maximum temperature, the mean temperature, the mean relative humidity, the mean rainfall and the mean maximum rainfall, on a yearly basis, collected by 12 meteorological stations located all over Crete for the period of 1931 up to 2000. Data were averaged per decade period and mapped to show the trends that exist throughout the island (see Fig. 7 for data corresponding to the 1991-2000 decade period). Among other results, data clearly indicate the decrease of the rainfall levels and the increase of the mean temperature, which are critical factors in the desertification process.

5.4. Fires.

Fire incidences in the period of 1923-1997 have been recorded by the Department of Forestry of the Ministry of Agriculture. Their archives also include the number of fires and the total area affected in the vicinity of the villages, together with the type of vegetation burned.

These data were coded while circular buffers representing the total area affected were created around the location of the corresponding villages. Thus, a number of thematic maps were created indicating the size of the burned areas and the number of fires per modern settlement (fire frequency) (Fig. 8). Unfortunately, there are no maps showing the exact outline of the burned areas.

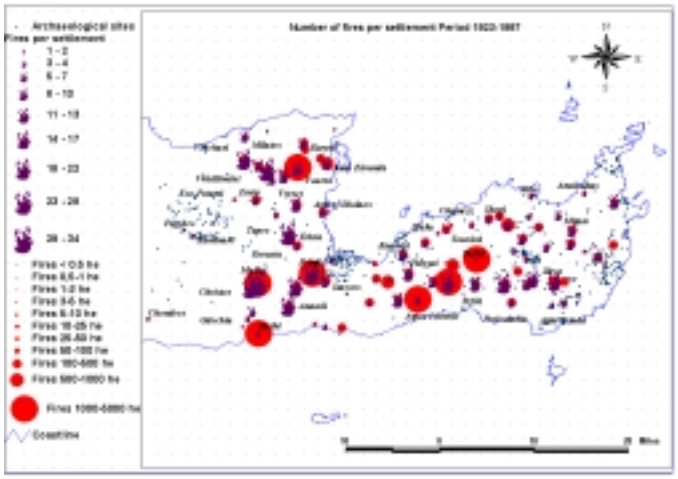

Fig. 8. Frequency of fire incidences per archaeological site and total area infected. Data covering the period of 1923-1997.

5.5. Earthquake activity.

Historical data concerning the earthquake activity before 1950 were collected by Papazachos & Papazachou (1997) and Papazachos *et al* (1997). Data include the date, epicentre and magnitude of earthquakes before the 1950's. Data for earthquakes after 1950 were obtained by the web site of the Institute of Geodynamics of the National Observatory of Athens (http://www.gein.noa.gr/services/cat.html).

Only earthquakes with magnitudes larger or equal to 4.5 R were included in the database. The geographic coordinates of their epicenter (latitude, longitude) were transformed into Easting and Northing of the Greek Geodetic Reference System 1987 (EGSA'87). Thus, a point shapefile was created, containing the epicentres, date and magnitude of earthquakes from 1900 to 2001. Earthquakes were classified in 8 main categories, based on their magnitude (4.5 - 4.9 R, 5 - 5.4 R, 5.5 - 5.9 R, 6 - 6.4 R, 6.5 - 6.9 R, 7 - 7.4 R, 7.5 - 7.9 R and >7.9 R). A simplified model showing the areas affected by the earthquakes was created by constructing circular buffers of different radii for each category of magnitude. For example, 3 buffer zones, 5km in width (a total of 15km from the earthquake's epicentre) were created for earthquakes of magnitude 4.5-4.9R (Fig. 9). 3 buffer zones, 30km in width (a total of 90km from the earthquake's epicentre) were created for earthquakes of magnitude 6.5-6.9R.

Buffer zones helped to distinguish the specific earthquakes that affected the archaeological sites at Lasithi. Based on the above classification scheme, it was found that only 36 out of a total of 523 earthquakes from 1900 to 2001 were responsible for affecting the archaeological sites at Lasithi. Buffer regions were also spatially joined with the location of the archaeological sites, in order to examine the type of sites mostly affected by the earthquake activity in the last century.

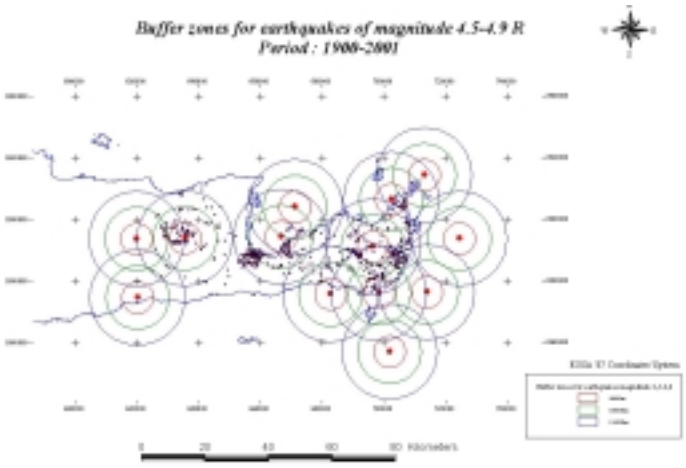

Fig. 9. Buffer zones for earthquakes of magnitude 4.5-4.9R. Period of 1900-2001.

Examination of the 1st buffer zone (buffer zone A or high-risk area) around each epicenter has shown that 422 sites out of the 717 fall within the high-risk zone. 76,67 % of the sites fall within the buffer zone A of 1 earthquake, 13,10 % from 2 and 10,24 % from 3 earthquakes. Finally, the statistical correlation between the 1st buffer zone of earthquakes and the archaeological sites containing architectural relics (470 out of the total of 717 sites) was examined.

It has to be mentioned that the above analysis is quite simplistic, as it does not take into account the depth of the epicenter, the isoseismal maps, the seismic wave propagation direction, etc. However, it is indicative of the risk factor that can influence the archaeological sites of the region.

Fig. 10. Buffers. Archaeological sites located at a distance of 0-50m away from the main road network.

5.6. Proximity to modern topographical features.

The proximity of the archaeological sites to modern topographical features was also examined. Buffer zones of different width were created along the main and secondary road network (Fig. 10), the coastline, the modern villages, the certain and possible fault lines, etc.

5 Risk Zone Definition. Towards a CRM Approach.

The above data were statistically analysed for defining the weights of influence of each parameter and the way that each one contributes to the designation of the archaeological risk zone. A

number of tests was applied by defining different weights to each variable and examining the outcome of the process with respect to the actual data, namely, the observed preservation status of each site, especially those falling in the high risk category (Fig. 11 & 12).

Fig. 11. Risk Variability of Archaeological sites. Experimental application of the definition of risk zones, based on the proximity to urban environment & coastline, seismic activity, fire frequency, soil depth and erosion.

Further research is under progress in an effort to include as many parameters as possible in an effort to refine the risk-zone definition model and depart from the siplistic approach of other similar studies (Fig. 13). The ultimate goal of the project is to include the whole island of Crete and create an interactive interface, in which the final user will be able to define the weights of influence in an interactive way.

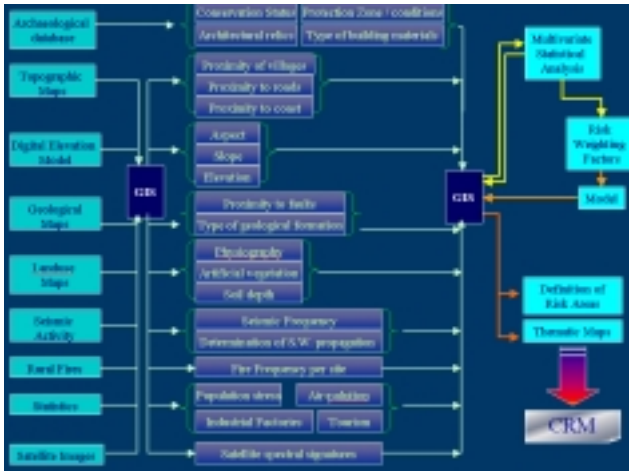

Fig. 13. Design of a sophisticated archaeological risk-area definition model, based on a GIS approach.

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Fig. 12. A number of sites found in bad preservation status were also included among the sites that have been found in the high-risk zone defined by the above model. Above, Agios Georgios – Papoura, with signs of habitation (sanctuary, settlement and burial site) during the Middle Minoan, Dark Ages and Roman periods, has been partially destroyed due to an antenna construction. Middle, the Neopalatial villa of Klimataria, partially destroyed due to the construction of the road connecting Sitia with Piskokefalo. Below, Pelekita, a probable quarry of the palace of Kato Zakros, threatened by its closeness to the sea.