International Symposium and Field Seminar on
Present State and Future Trends of Karst Studies
September 17-26, 2000 - Marmaris, Turkey

A GIS BASED ASSESSMENT OF RESOURCES FOR THE KARST ISLAND OF GOZO

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ABSTRACT

The island of Gozo was selected as a study area in an EU sponsored research project on 'Resource Management in Karstic Areas of the Coastal Regions of the Mediterranean'. An overall research objective was to devise a system that permits to assess the state of the different environmental resources, their importance and their vulnerability. A detailed inventory of data requirements was drawn up that included water, soil, biodiversity, forestry, and the karst heritage. Data collected from bibliographic studies, aerial and field surveys were stored using the Integrated Land and Water Information System (ILWIS). Using its GIS capabilities, new insight was gained about interdependencies between the various resources. Finally, it is demonstrated how the system was used to apply a known, statistically based, approach to regional landuse planning, adapted to take into account the special conditions associated with a coastal karst environment.

1. INTRODUCTION

The Maltese Islands, like many other countries in the Mediterranean, are at present experiencing rapid resource depletion and environmental deterioration due to demographic, social, cultural, political and economic pressures. Moreover, these pressures are particularly made evident because of the fragility of the environment: karst landscapes are more prone to demonstrate negative impacts in the short term than other types of terrain. The EU sponsored research project, 'Resource Management in Karstic Areas of the Coastal Regions of the Mediterranean', was focused precisely on these issues for selected study areas in Turkey, Lebanon and Malta respectively. The application and adaptation of the '*Schema d'Amenagement et de Gestion des Eaux'* (SAGE) methodology to cater for the planning and management of the environmental resources for the island of Gozo is expanded by the authors in another paper presented at this Karst Symposium. Here, we expand on the role and outputs achieved from the use of GIS as an information management system in the context of the SAGE methodology.

2. CONSTRUCTION OF ENVIRONMENTAL RESOURCE DATABASE

At the very start of the project, a detailed inventory of information requirements was drawn up for each of the environmental resources, i.e. water (comprising surface water, groundwater and bathing water quality), soils, geology, biodiversity and forestry. This inventory was extended to include information on the karst heritage features, such as caves, dolines and sinkholes, as an environmental resource in their own right. Furthermore, it was decided to consider also the cultural heritage features for the Gozo study area. For each of these environmental resource "covers", parameters were identified which could serve to describe the state (condition) of the resource, its use and relevant socio-economic data. Additionally, for each parameter, attribute information concerning the source of the information, the scale of data capture and the data quality (based on a combined assessment of age, completeness and reliability of the data), were stored as attribute information in the database.

2.1 Data collection approaches

Following the examination of this initial inventory, it was verified for each of the resource parameters whether these were available, missing, outdated or required in more detailed form. This was complemented with an investigation into the various possibilities in acquiring aerial photographs and satellite images. Since at this stage it was not clear to what extent existing data was valid or reliable, it was concluded to go for a combined use of aerial photographs, field surveys and satellite image interpretation. This approach enabled to improve on the completeness and accuracy of several data sets, such as the location and attribute data for livestock rearing establishments, horticultural activities and many more.

While at the outset of the research, it was attempted to maintain a standardised approach for the data collection in the three Mediterranean partner countries, the use of a common landcover legend in particular presented some difficulty when applied to the Gozo study area. The use of the CORINE landcover classification as a common reference basis did not provide a sufficient degree of spatial variation. For example, in the absence of 'forests' on the island of Gozo, the CORINE output did not reveal the substantial number of wooded areas that are present. Undoubtedly, these wooded areas contribute significantly to the perception that Gozo looks a lot greener than the main island of Malta. In consultation with the Department of Agriculture, the landcover legend was therefore expanded to much greater detail. Table 1 illustrates the expansion of forest to "Forest and shrub areas", while similar considerations were used to expand on "Man-made areas", "Agricultural areas", "Unproductive areas" and "Water and wet areas".

Table 1 Adaptation of landcover classification for the island of Gozo

C	Forest and shrub areas	C1	Wooded areas	*C11*	*Native wooded areas*
				C12	*Eucalyptus*
				C13	*Acacia*
				C14	*Other non-native wooded areas*
		C2	Maquis	*C21*	Maquis
		C3	Garigue	*C31*	Garigue
		C4	Cane (*Arundo Donax*)	*C41*	Cane *(Arundo Donax)*

Obviously, the Gozo landcover map provides the predominant "cover" for every individual tract of land. However, by means of detailed field surveying, the relative occurrence of selected types of trees and perennial tree crops was recorded for each of individual field. Hence, the 'isolated', 'abundant' or 'dominant' occurrence of carob, citrus, fig, grapevine, olive, prickly pear, and walnut was stored as attribute data to the landcover layer. Similarly, by recording the use of cane, prickly pear and/or stone walls as windbreakers, a large array of additional maps was produced for the very first time. The examples below illustrate the additional information concerning the spatial distribution, existing and/or potential use thus obtained:

a) the carob tree, which is a native, was found mostly beneath the escarpments of inland hills. From the carob tree, carob honey and carob health creams are made;

b) the distribution of the non-native eucalyptus “groves” which are planted for bird hunting purposes and are found on many hillslopes throughout the study area give an indication of the large (and alarming) tracts of land used for bird hunting. Furthermore, local biodiversity experts consider the eucalyptus an intrusive species;

c) the fast growing prickly pears are often utilised as windbreakers, bordering open fields. However, these same trees also serve as fodder for animals. The very high occurrence of prickly pears, together with the large tracts of land with cereals grown also as animal fodder, give an indication of the large number of animals that are reared on the small island of Gozo.

2.2 Alternative Data Collection Methods

The extensive datasets that became available following a second major field surveying campaign enabled to fill several gaps in the information. Nonetheless, specific difficulties remained in relation to establishing surface water quality, aquifer thickness and soil attribute information.

With the assistance of Dr. Sylvia Haslam, river ecology expert at the University of Cambridge, an alternative approach - i.e. through vegetation monitoring - was developed to arrive at an indicative surface water quality map, given the absence of direct water quality measurements. Evidently, this approach requires running water in streamcourses over a prolonged period of time so that the plant species, which are used as indicators of the water quality, can establish themselves. This hydrological condition was satisfied only during the final hydrological year of the project, due to below average rainfall over the previous two years. Further information on the use of plant indicator species to produce a water quality map of the watercourses in Gozo can be found in Haslam (2000).

In the absence also of any piezometric data for the Gozo Study Area, a simpler approach based on a number of general assumptions was adopted to establish an aquifer thickness map, while the successful interpretation of attribute information on soils was obtained following consultations with FAO soil experts through the assistance of the Joint Research Centre at Ispra, Italy.

3. GIS BASED ENVIRONMENTAL RESOURCE ASSESSMENT

Digital entry of the different environmental resource parameters that were collected, was performed using the Integrated Land and Water Information Management System (ILWIS), developed at the International Institute for Aerospace Survey and Earth Sciences (ITC) in Enschede, the Netherlands. Using its GIS functionality, the production of maps in point, segment, polygon and raster format could be easily obtained. Thus, with reference to the first step in the SAGE philosophy, a set of thematic maps describing the state and use of the different environmental resources was obtained.

The ILWIS user-friendliness became particularly evident however when using its in-built features to provide statistics and histograms, as well as for the purpose of looking at the cross-correlation between different datasets and maps. This was most important in relation to the second step in SAGE, i.e. for the diagnosis of the environmental resources.

Major successes were achieved among other with regard to the preparation of a surface water drainage map. The establishment of pollution indices through vegetation monitoring, described earlier, confirmed the otherwise common occurrence in karst areas of streamcourses conveying water over limited stretches only for a prolonged period of time after a rainfall event. In order to establish a more complete drainage network therefore, the precise location of cane (*Arundo Donax*) was plotted, as an indicator for the presence of water flowing just below the surface. Hence, the superimposition of the cane with the digital elevation model (DEM) map, enabled the tracing of an updated and reliable drainage network map.

The production of a water resources vulnerability map was yet another novel output for the island of Gozo. The '*Surficial Cover Infiltratrion (SCI)'* algorithm was developed among the Mediterranean partners of the project, and is based on a combined assessment of four contributing factors: surface lithology, fault density, karst features density and drainage density, assigned with the following weights:

Table 2 Weights assigned to Surficial Cover Infiltration factors

'SCI' FACTOR	WEIGHT (%)
1) Surface Lithology	35
2) Lineament	20
3) Karst Features	30

4) Drainage Density	15

The detailed interpretation of the SCI map obtained for the island of Gozo, showed a most satisfactory result in respect of surface lithology, fault density and karst density. Areas with a higher fault density and/or karst features density were assigned correctly with a higher infiltration rate. Conversely, the infiltration rate was reduced correctly in areas where blue clay forms the outcropping formation. However, the effect of the drainage density factor was not understood from this initial SCI map. The proposed algorithm tackled the drainage density factor in a similar way as was defined for the lineaments, i.e. streamcourses were traced for the entire study area and the resulting streamlengths were categorized into either 'low', 'medium' or 'high'. For the Gozo study area, the computation of the drainage density for each of its 40 catchments always yielded values less than 2 kilometre per square kilometre. On the basis of this observation, the drainage density was judged to be 'low' for the entire island, and was therefore assigned a maximum SCI rating of 3 in respect of the drainage density factor. A revised SCI map for the island of Gozo was then retained.

Another interesting diagnosis was made with respect to the occurrence of soil erosion. A map showing the surface water induced land degradation features proved to correlate extremely well with a map showing the physical condition of the rubble walls on the island. These loose stone walls provide a centuries' old form of terracing, thereby acting as an effective means to guard against soil erosion, apart from their purpose to delineate field ownership. While legislation does require that these walls should be adequately maintained, a poor to very poor condition of these walls was found in many areas, and most notably in areas where a high incidence of soilslumps had been recorded.

4. A STATISTICAL APPROACH TO REGIONAL LANDUSE PLANNING

The final year of the project was devoted mostly to the testing and validation of methodologies that would facilitate further the integrated planning and management of the environmental resources. The underlying philosophy was to devise a means to divide the study area in a number of territorial reference units (RMM Units) and then to transpose all the GIS data layers into a statistical database attached to these Units.

Within the SAGE methodology, the term 'reference unit' is used to denote the hydrological basin, which therefore serves as the basic territorial reference unit in the French law. The objectives of these basic units are clearly identical to the objectives of the RMM Units, but required a major adaptation of the SAGE methodology. For the purpose of water resources management, the hydrological basin and the catchments within the basin are clearly the 'optimum' territorial reference units. This is not a priori transferable when it comes to the management of all the environmental resources, which was the scope of the present research.

Conceptually, the RMM Units were defined with the objective to provide a spatial representation of the karst structure and functioning. Considering the widely accepted recognition that the other environmental resources (soil, biodiversity, forest etc.) are all linked to the water resources, the obvious starting point was to look at the special vulnerability of karst aquifers in relation to water resources management, which has been the object of several important research studies in recent years.

The Guidelines issued from Cost Action 65 (1995) advise that "a karst system may be defined by its framework (provided by the geology), by its structure of underground flow paths and by its hydraulic behaviour". It follows that the main characteristics of karst aquifers are in relation to the infiltration conditions and the recharge mode".

Consequently, it was decided to test the RMM Units that would be obtained from the crossing of the geology, watershed and Surficial Cover Infiltration (SCI) maps, i.e. the covers which could be considered to best represent the dynamics of the karst system. Some elementary statistics on the number and size of the units obtained from selected example crossings is provided in Table 3. As will be explained in more detail later on, a map showing the administrative boundaries within the Gozo study area was also used in these trial crossings.

Table 3 RMM Unit Cover selection: some elementary statistics

RMM Unit Cover	Resulting from crossing of	Number of Units	Average Unit size (ha)	Maximum Unit size (ha)
1	Geology + Watershed	630	10.4	326
2	Watershed + SCI	344	18.8	280
3	Watershed + SCI + Local Councils	514	12.5	186

4.1 Creation of RMM Unit statistical databases

The next logical step involved the setting up of criteria to decide on the optimum RMM Unit cover among the alternatives. First, the various information layers that were stored in the GIS database for the Gozo Study Area were linked to the RMM Units in the following manner:

a) each information layer (e.g. soil, landuse, habitat etc.) was crossed with the RMM Unit map, thereby providing - for each crossing:
b) an attribute table (e.g. RMM Units crossed with Soils), in which the precise surface area covered by each soil type for each RMM Unit can be found.
c) this information was then transcribed into the so-called RMM Unit database as follows:
   - for polygon information layers, the RMM Unit database stores a percentage value, computed by 'Area of Intersection divided by Area of RMM Unit':
     e.g. Area of Soil Type "A" is divided by Area of RMM Unit No. 1, and is expressed as a percentage value. This calculation is made for each RMM Unit and stored in a column "%Area_Soil_type_A". The same process is then repeated for each soil type;
   - for information taking the form of a segment map, the RMM Unit database stores a density type of value, computed by 'Length of Segment divided by Area of RMM Unit'; while
   - for point data, the RMM Unit database stores a "count" type of value, computed by 'Number of points in each RMM Unit'.

4.2 Comparisons between RMM Unit statistical databases

A typical type of query could now be formulated, for example: show the RMM Units with more than 50% man-made area. Comparision between the outputs demonstrated that a progressively better representation of man-made areas was retrieved as the number of RMM Units increased, a result expected also from the application of the Lorenz curve and the Gini coefficient. This first conclusion was confirmed from the comparison between the outputs of similar queries in respect of soils, habitats etc., and allowed to describe the validity of the RMM Units as follows:

- Best representation found with Geology + Watershed (630 RMM Units)
- Followed closely by Watershed + SCI + Local Councils (514 RMM Units)
- Least valid representation with Watershed + SCI (344 RMM Units)

However, this represented a rather optimistic evaluation. When repeating the same exercise at the most detailed level of the landcover classification (see last column in Table 1), the occurrence of e.g. wooded areas was no longer retrievable in the RMM output maps. At least, not unless the threshold was lowered significantly from the 50% mark to as low a threshold as 5% in many cases.

Evidently, the purpose of the RMM Unit covers is not to compete with the original data information layers, but rather to enable additional types of queries concerning the state and use of the resources. Particularly the scale of data capture may have presented an obstacle in this respect: since the exact location of very detailed information is now readily available from the GIS, it is not a priori clear to the planner and/or decision-maker what extra information can be obtained from the RMM Unit Covers.

5. LOCAL COUNCILS USED AS TERRITORIAL REFERENCE UNITS

It proved most worthwhile to apply the RMM Unit approach to the creation of a statistical database, tied to the Local Councils in the Gozo Study Area. Indeed, it was observed that each of the statistical databases tied to the RMM Unit covers described earlier, failed to represent the 'uncontrolled urbanization' which was identified as one of the most significant impact scenarios for the entire Gozo study area. While a fairly good representation of the urban area was found for the large towns in the central part of the island, the seaside resorts of Marsalforn and Xlendi were clearly not represented satisfactorily. Yet, each of the latter villages is definitely subject to a very high level of uncontrolled urbanization. This apparent anomaly is very likely because the actual growth of urbanized area, especially in these seaside resorts, corresponds to a linear extension of residential and tourist developments, along roads and natural escarpments. This linear expansion is impacting dramatically on the scenic value of the landscape (escarpments and valleys).

Using the Local Councils map as a territorial reference (RMM) Unit map, and linking the environmental resources to these existing administrative divisions of the Gozo Study Area, did permit a novel way to demonstrate the scarcity of the resources: e.g. percentage of remaining garigue and maquis areas in each Local Council. Most interestingly, the uncontrolled urbanization along Gozo's valley roads can also be shown statistically - e.g. as a percentage of valley course length already affected by urbanization.

Finally, by analogy with the SAGE approach, the regional planning and management of environmental resources could be assigned to "Local Environment Commissions". Clearly, the implementation of this approach would be facilitated greatly if the area of jurisdiction of each such commission would respect - or even borrow - the existing regional administrative divisions. For the Gozo study area, this would mean the setting up of an Environment Commission for each Local Council. There are 14 Local Councils in Gozo, with an average surface area of 4.7 square kilometers. This simple and straightforward division of the study area also results in a practicable number of territorial reference units.

Acknowledgements

The financial support received from the European Commission to the INCO-DC project ERBIC18CT970151, Resource Management in Karstic Areas of Coastal Regions of the Mediterranean (ResManMed) is gratefully acknowledged.

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