



ΥΠΟΥΡΓΕΙΟ ΑΝΑΠΤΥΞΗΣ - ΓΕΝΙΚΗ ΓΡΑΜΜΑΤΕΙΑ ΕΡΕΥΝΑΣ ΚΑΙ ΤΕΧΝΟΛΟΓΙΑΣ  
MINISTRY OF DEVELOPMENT - GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

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## **Report on Land use changes, vulnerability and groundwater pollution risk mapping in Falasarna Catchment.**

### **1. Introduction**

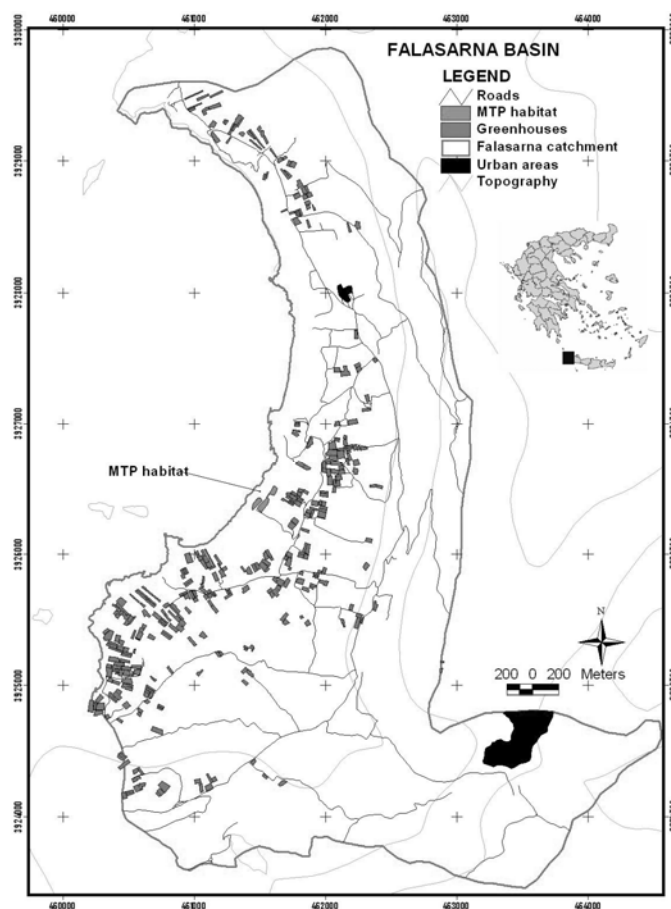
Wetlands and semi-aquatic habitats undergo significant stresses today due to direct human interventions such as land use changes and resource overexploitation while climate change also plays an important role in the hydrologic destabilization of these habitats. Mediterranean Temporary Ponds (MTPs) is a priority freshwater habitat according to the European Natura 2000 network (EC/92/43) developed in very shallow depressions with standing waters that are flooded for only a few months in winter and late spring and incorporate mainly Mediterranean therophytic and geophytic vegetation (EUR25, 2003). This habitat presents significant variability in its geomorphologic, hydrologic and physicochemical characteristics at the various areas that is found (Angélibert 2004, Boix et al. 2004, Boix et al. 2001, Grillas et al. 2004, Jakob et al. 2003). The ponds' size may fluctuate from less than 1m<sup>2</sup> up to several hundred m<sup>2</sup> while their hydroperiod (duration of flooding phase) varies significantly at different latitudes (from days to months) depending on the dominant climatic conditions and geological substrate. These unique characteristics that are not encountered in many other habitat types allow the development of rare fauna and flora species that are very important for the conservation of biodiversity. In the island of Crete there are 5 MTP sites which represent approximately 26% of the total number of MTP sites in Greece. Some of the most important threats of the particular sites are water pollution mainly due to agricultural activities, cropland expansion in areas occupied by ponds and soil excavation for greenhouse construction. These stresses are further enhanced by the lack of a cadastre system in Greece which allows an uncontrolled extension of private land against public and especially to ecologically significant areas.

Risk mapping for groundwater protection is a relatively new approach (Zwahlen, 2003) that has been developed during the last decade with the use of GIS and other cartographic tools (Dixon 2005). It is a relatively fast and efficient way of demonstrating/displaying/presenting areas that are prone to groundwater pollution because of its hydrogeological and land use conditions. The risk maps produced could be used by local authorities and environmental managers to support planning processes and avoid future developmental activities with high pollution risk. Moreover, the particular information can be used in designing conservation and restoration measures for already degraded areas such as the study site which hosts significant endangered habitats.

This study aims to quantify pressures and impacts from human activities on the MTP's of western Crete (Falasarna bay) focusing on land use changes and groundwater pollution by using risk mapping and GIS techniques.

## 1.1. Description of the area

Falasarna basin is a semi-mountainous coastal area located in the western part of Crete island. Its coastline has a length of approximately 6 km and the elevation of the basin fluctuates from sea level in the west to 300m in the eastern part of the catchment which has an extent of 12.4 km<sup>2</sup>. The area belongs to the Natura 2000 European protection network (code: GR4340001) since it hosts a significant number of endangered habitats and species such as the Mediterranean Temporary Ponds. The main economic activities are agriculture and tourism and during the last 3 decades a considerable increase in the number of greenhouses and the area of cropland has been observed. The geology of the area comprises mainly calcareous rocks (limestone) and neogene deposits in the lowland,. The topographic slope is relatively low in the coastal and central zone and increases close to the eastern boundary of the catchment. The MTP habitat is located in the western part of the basin close to the coastline (figure 1) and is seasonally affected by the heavily polluted groundwater.



**Fig. 1. Map of the study area**

## 2. Methodology

The Falasarna Bay aerial photos for the years 1970 and 2000 have been acquired by the Greek Military Service in a 1:15.000 scale. These photos have been digitized, imported in ArcView software (GIS) and georeferenced by using the EGSA '87 coordinate system. The Image Analysis component of ArcView has been used to classify the different land categories (of the images) based on a supervised classification approach. For a better substantiation of the results deriving from the land use mapping, in situ surveys were undertaken and relevant data from local authorities was

examined. The land use maps of the years 1970 and 2000 were created and their comparison followed with the use of Spatial Analyst package to quantify the observed changes in the land categories (greenhouses, cropland, urban areas, natural areas/forests). The vulnerability map of the local aquifer, hydraulically connected to the ponds, was thereafter produced by using geological and soil information. The hydrologic properties of the aquifer were also incorporated in the GIS software used for the creation of the map. The vulnerability mapping followed the specifications suggested by the EU program: Cost Action 620 (Zwahlen, 2003). This program proposed a 'European approach' by assessing several scientific approaches for vulnerability and risk mapping aiming at the protection of Carbonate Aquifers. The methodology of the current study proposes the production of maps describing the flow regime of the catchment examined (C map) and the overlying protective cover of the aquifer (O map). The aquifer's intrinsic vulnerability map is developed by combining these two maps (O and C maps).

The map expressing the Overlying soil layers protective function (O map) has been produced with the use of the area's geological map and bibliographic soil information. A combination of the thickness and permeability of the overlying layers was used for each soil formation in order to define for each one a protective value index. The areas of the catchment that had the same or similar index values were grouped into areas of high, low and medium protective cover and projected in a GIS environment. The infiltration conditions and the potential for concentrated flow towards the aquifer were also assessed with the use of C map. The area was divided into high, low and medium flow concentration focusing on aspects such as the existence of direct infiltration, surface runoff and sinks.

The hazard maps of the area for the years 1970 and 2000 were produced by assigning hazard values (from 1:low to 5:high) to different land categories in order to express the pollution potential for each category. The risk maps regarding aquifer pollution for the years 1970 and 2000 were finally produced with a combination of the groundwater vulnerability maps and the hazard maps of the study period.

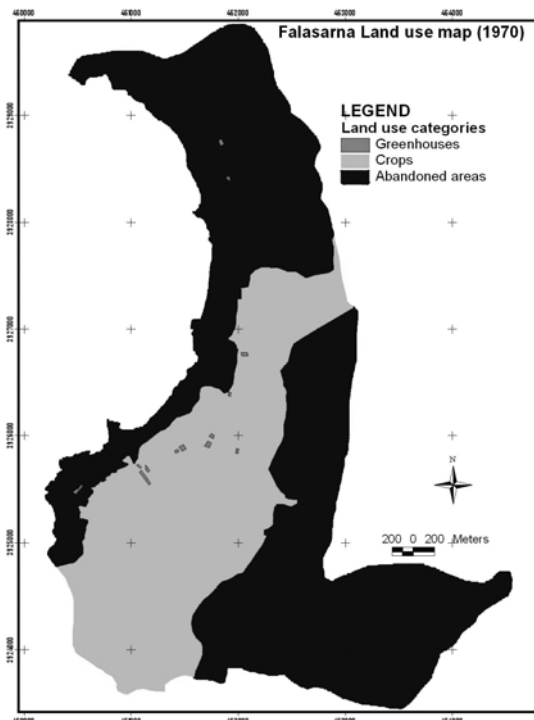
### **3. Results**

#### **3.1. Land use change detection**

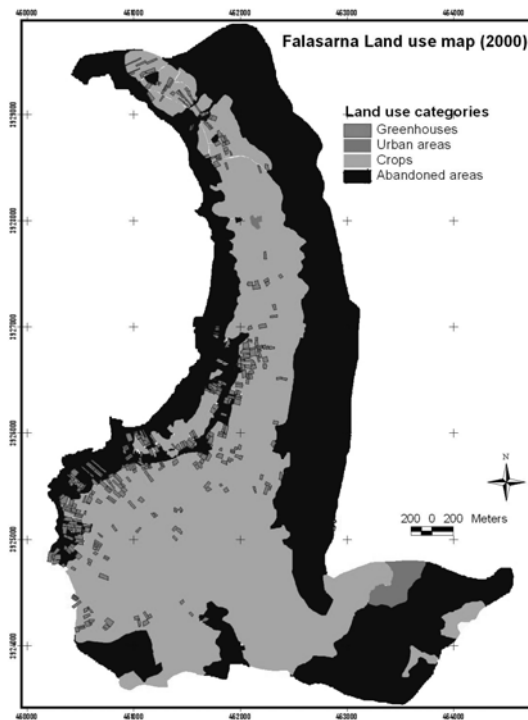
The land use maps of the year 2000 (figures 2 and 3) illustrates that a significant part of the study area is occupied by agricultural land (48%) while the natural areas present a lower value (47%). Moreover, the comparison between the maps of 1970 and 2000 illustrate that there is a substantial decrease for the natural – abandoned areas during the particular period (46.5%) while on the contrary cropland had expanded by 48.5% in relation to the 70s value (table 1). The same pattern is observed for the greenhouses since in 1970 there were only 13 greenhouses and in the year 2000 have reached more than 260 (2071% increase). This development has detrimental implications for the groundwater pollution potential and the existing ecosystems in the area. The agricultural land has also increased by 34% in relation to the 1970's respective coverage and the natural areas were reduced by 27%. Another important aspect of the examined land use changes is the spatial distribution of the greenhouses that are mostly located close to the coastal zone where the MTP's are situated and very popular bathing waters exist.

**Table 1. Land use changes in the period 1970 - 2000 in Falasarna catchment**

Land categories	1970 (m <sup>2</sup> )	% of the catchment area	2000 (m <sup>2</sup> )	% of the catchment area	Change rate (%)
<b>Cropland</b>	4486770	36.2	6011201	48	<b>48.5</b>
<b>Natural forests</b>	7893136	63.6	5776602	47	<b>-46.6</b>
<b>Greenhouses (no)</b>	13	0.0	262	-	
<b>Greenhouses (area)</b>	21618	0.2	469390	4	<b>3.8</b>
<b>Urban areas</b>	0	0.0	138676	1	<b>1.1</b>



**Fig. 2. Falasarna land use map of 1970**

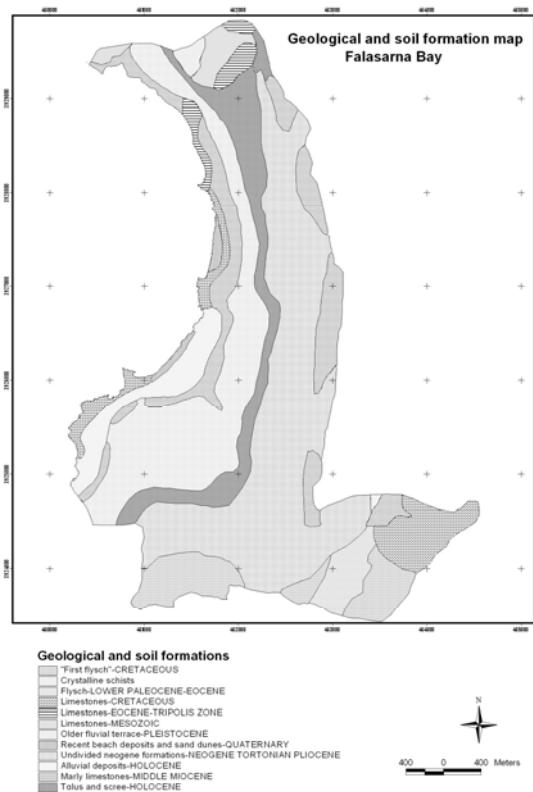


**Fig. 3. Falasarna land use map of 2000**

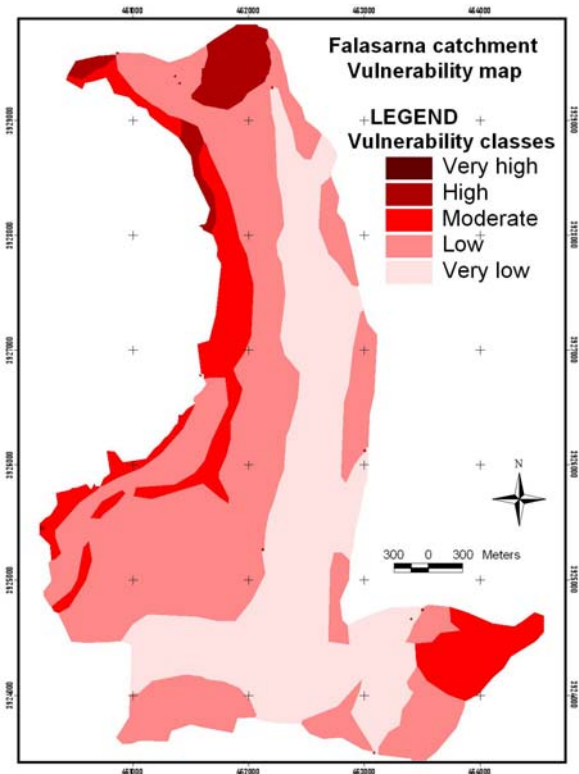
### 3.2. Vulnerability mapping

The geology of the area comprises mainly highly permeable calcareous formations that underlay the entire catchment and has outcrops in the eastern mountainous areas as well as in the coastal zone. The surface extent of these karstic formations is 2.7km<sup>2</sup> representing approximately 22% of the study catchment. In the central part of the particular area pleistocenian and tertiary sediments are encountered covering 67% of the catchment and constituting a significant protective soil cover for the aquifer but at the same time hosting the most hazardous land categories such as agricultural areas and greenhouses. The low permeability flysch formations and schists cover only 11% of the catchment and have sporadic appearance mainly in the higher elevation zones (figure 4).

The vulnerability map developed after combining the protective function map (O map) and concentration of flow map (C map) indicates the zones of high, low and medium vulnerability regarding groundwater pollution from a hydrogeological point of view (figure 5). Thus, the eastern part of the catchment and most of the coastal zone where karstic formations are encountered is characterized as highly vulnerable area while the central part of the catchment where the protective coverage of neogene sediments exists is classified as of medium vulnerability. This approach focuses on the main karstic aquifer of the catchment and does not include potential low size and low productivity aquifers that may be formed temporarily in the sedimentary deposits of the lowland. Therefore, the use of the vulnerability map by the planning authorities should be done in combination with several socio-economic and environmental aspects such as the location of ecologically significant habitats and recreational infrastructure. To overcome this difficulty and present more important information for the local authorities, the development of the groundwater risk map followed by superimposing the hazard map (weighted land use map) on the vulnerability map.



**Fig.4 Geological map of Falasarna catchment**



**Fig. 5. Vulnerability map of Falasarna catchment**

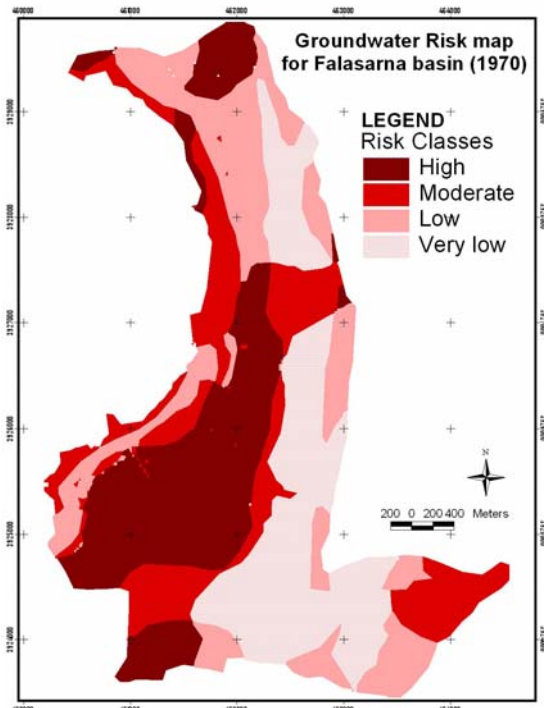
### 3.3. Risk mapping

The risk maps of the area for the years 1970 and 2000 indicate that the high risk zones for groundwater pollution coincide with the central part of the catchment where the agricultural fields and some greenhouses exist. These potential highly hazardous elements in combination with the medium vulnerability sediment formations increase the risk of aquifer pollution incidence through both point and non-point sources. It is clearly illustrated in the maps (figures 6 and 7) that there is a great increase of moderate and high risk zones (69%) from 1970 to 2000 contributed to the increase of agricultural land. The low and very low risk zones have decreased over the same period by 31% and 36%, respectively, due to cropland expansion. In addition, greenhouse development led to the

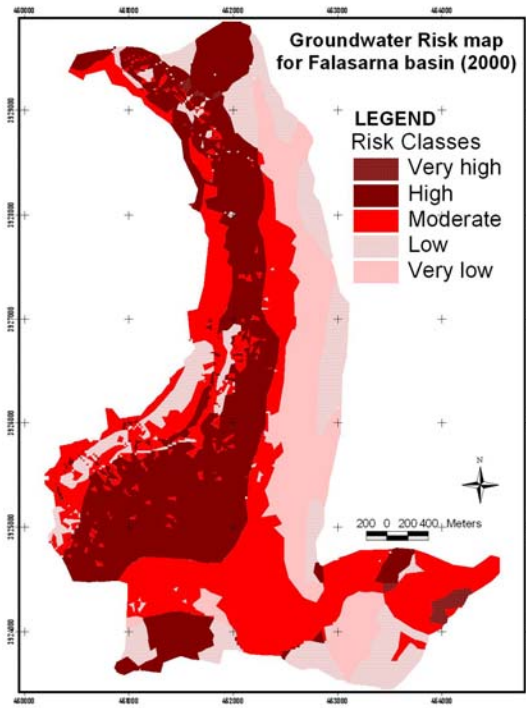
appearance of new high risk spots close to the beach and to the MTP habitats (table 2). The low and very low risk zones existing in the year 2000 map are semi-mountainous areas in the northern and southeastern part of the catchment (figure 7) and cover only 34% of the catchment's total surface. Furthermore, the very high and high risk zones covered 35% of the watershed area by 2000, while the medium risk zone covered the remaining 32% (table 2).

**Table 2. changes in the groundwater pollution risk zones of Falasarna catchment**

Risk	1970	% of the catchment area	2000	% of the catchment area	Change rate (%)
	(m <sup>2</sup> )		(m <sup>2</sup> )		
Very high	0	0	95711	1	-
High	3454892	29	4106052	34	19
Moderate	2546354	21	3822944	32	50
Low	2889864	24	1986676	17	-31
Very low	3141203	26	2023259	17	-36



**Fig. 6. Groundwater pollution risk map for Falasarna catchment in 1970**



**Fig. 7. Groundwater pollution risk map for Falasarna catchment in 2000**

#### 4. Discussion – conclusions

The use of remote sensing and GIS techniques in the particular study for land use change detection and for mapping of groundwater pollution risk indicated that during the last 30 years significant alterations in the land use regime occurred in the Natura 2000 site studied, leading to approximately 20 % increase of high risk zones. The lowland part of the catchment where most of the human interventions are found such as agricultural land and greenhouses presents the highest possibility for groundwater pollution while the low and very low risk zones are limited to 17% of the watershed,

mainly in mountainous areas where few anthropogenic pressures exist. Therefore, these findings coupled with the fact that the area belongs to the Natura 2000 protection network, due to the significant habitats observed there, create the necessity for the responsible management authorities to take immediate mitigation and restoration actions to avoid further environmental degradation. A local cadastre system should be developed in order to limit the continuous expansion of agricultural land while the construction permits for new greenhouses should be controlled. Measures to restore the water quality of the aquifer which is very low should be undertaken, as it is also a requirement of the Water Framework Directive (2000/60/EC) for all the EU countries. The produced maps could be used in combination with other socio-economic and environmental data to support decision making processes regarding future developmental activities under the framework of environmentally-friendly and sustainable investments.

Similar risk mapping approaches have been recently applied successfully in many European countries (Zwahlen, 2003) and in the US (Dixon 2005). The results of these studies indicated that vulnerability and risk mapping for groundwater protection is an approach that can contribute together with other complementary tools and information to the integrated environmental planning and management. However, the outcome of this process should be relatively simple and easy to use by local authorities and non-expert users.

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