Integration of Geographic Information Systems in Technological Education. An example in the Geo-environmental sciences

MARIA KOULI (1), DIMITRIS ALEXAKIS (1), FILIPPOS VALLIANATOS (1), PANTELIS SOUPIOS (1), APOSTOLOS SARRIS (2), AIKATERINI XEPAPADAKI (1), NANTIA ZOUMPOULOGLOU (1)

(1) Department of Natural Resources & Environment,
Technological Educational Institute of Crete
Romanou 3, Halepa, 73133, Chania, Crete
GREECE
mkouli@chania.teicrete.gr, http://www.chania.teicrete.gr
(2) Institute for Mediterranean Studies, Foundations for Research & Technology, Hellas (F.O.R.T.H.)
Melissinou & Nik. Foka 130, 74100, Rethymno, Crete, Greece
asaris@ret.forthnet.gr, http://www.ims.forth.gr

Abstract: - In this work we provide a description of a problem-solving under-graduate research project which is being carried out in the Department of Natural Resources & Environment of Technological Educational Institute of Crete, Greece. Geographic Information Systems and Hydrological data integration has been proved an efficient tool of learning process associated with technical skills. A multi-layered decision-making module that provides feedback and allows multiple final solutions is proposed. Apart from the pure educational character of the thesis, our aim is the quantification of the hydrologic regime of the Chania prefecture area and the development of a sustainable water management plan, which will be easily adopted from the local authorities. For this reason we have created several thematic maps using as source hydrological, hydro-geological, meteorological and elevation data.

Key-Words: - Geographic Information Systems, problem-solving research project, water management, Chania prefecture.

1 Introduction

Education in earth sciences is considered a cornerstone in the exploitation and economic development of water resources [1].
The proliferation of the use of digital data in teaching provides a set of opportunities and challenges for the development of earth sciences. Significant demand for persons who could utilize geographic information system (GIS) technology during the 1980s and 1990s led many academic institutions to establish undergraduate courses [1,2,3]. More recently in Greece, traditional classroom earth sciences courses have been linked with GIS courses to form concentrations, minors, diplomas or certificate programs.

Geographic Information System courses being implemented in the Geoinformation Laboratory of the Department of Natural Resources & Environment of the Technological and Educational Institute of Crete intend to develop science instructional materials to help scholars acquire the interest and expertise in aspects of science that utilize modern geotechniques, particularly applied to Earth Science, environmental science and resources management.

The goal behind teaching GIS should always be to provide under-graduate students with the skills and capacity to allow them to engage in active work after they have completed their studies. A key-element for securing skills-building is to guide them to learn the processes associated with tasks commonly used to conduct the type of work that is the focus of the training.

By learning the processes, under-graduate students will be able to apply the skills learned in different scenarios of interest. For example, in their most basic form, Geographic Information Systems generate digital data. The data come from different sources with different characteristics. From these data the under-graduate students must learn how to extract the necessary information for a specific application. They should be able to decide which techniques are most appropriate to use with the data they have access to, in order to obtain the most accurate spatial information possible to derive from the data available. Once the information is obtained they should be able to analyse the various layers or components created using analytical tools provided by a GIS environment. One of the most effective ways of teaching process is through the problem-solving under-graduate thesis.

This work provides a description of data and processes used in such a teaching project. In particular, it integrates Geographic Information Systems with hydrological and geological data. The purpose of this integration is to introduce the higher education students to the creation of several hydrological thematic maps of the Western Crete as well as the estimation of water budget since it is an essential and crucial task for the formulation of sustainable water management scenarios of the study area.

2 Hydrological Background of the Study Area – Using Geodata in Education

Crete is considered as a semi-arid region [4]. The average annual precipitation is estimated to be 900 mm, the potential renewable water resources 2650 million m^3/yr and the real water used about 485 million m^3/yr. The major water use in Crete is in irrigation for agriculture (84.5% of the total consumption) while domestic use is 12% and other uses 3.5% [4].

In Crete, water imbalance is often experienced because of temporal and spatial variations in the precipitation, an increase in water demands during summer months and the difficulty of transporting water due to the mountainous terrain [5].

The demand for irrigation water is high, while at the same time only 31.0% of the available agricultural land is irrigated [4]. The growing water requirements make the rational management of water resources extremely important for development to be sustainable and for the environment to be served.

To overcome the water shortage, especially in the future, several measures should be taken for conservation of water resources and protection of the environment. Our study is focused on the Western part of Crete, on the area of Chania prefecture (Fig. 1).

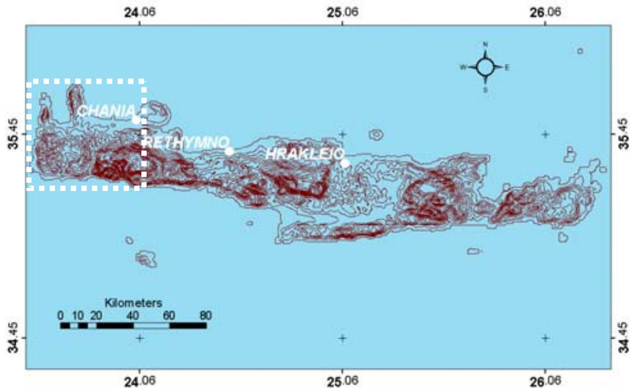


Figure 1. A map of Crete island. The study area is indicated with a dashed white square.

3 An Educational Approach to Data Acquisition and Data Analysis for Geosciences Students

In order to create the appropriate information platform upon which one could proceed in a systematic way towards the monitoring and management of the water resources it was essential to collect all the available data (hydrological, hydro-geological, meteorological, geological, topographic) as well as the maps (Fig. 2) which were used as the basement for the creation of the several layers (in the GIS sense).

In a next step we implemented all the data into a GIS environment and then we performed data digitization with the use of ArcGIS software package. The several maps were geo-referenced to the local projection system of Greece (GGRS ΄87 - Greek Geodetic Reference System) so that they can all be fused to the same projection system, together with all kinds of future information that may rise (e.g. cadastral data). All the information concerning the latitude and longitude of the data, were transformed to the GGRS ΄87.

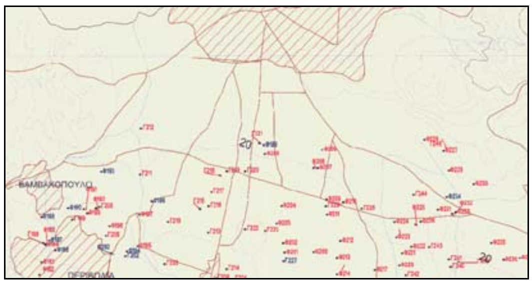


Figure 2. Detail of a hydrological map which was used as source for the digitization of the location of wells, springs and shafts of the Chania area.

3.1 Hydro-geological Data

The hydrological and hydro-geological data were collected from the Hydro-Geological study of Chania and provided from the Department of Hydrology of the Ministry of Agriculture. All the available information concerning the wells, springs and shafts of the broader area of Chania are gathered in these. These data are in the form of maps and card inventories (Figs. 3, 4).

The data contain important information such as the record code, the geographical coordinates of the data, the municipality and the close-by city or village, the maximum depth of the data (tubing depth, diameter of the tube, drilling depth, depth of the groundwater level), the water supply, the usage, the geological stratigraphic sketch of the data with a short lithological description and an in-situ time sequence of measurements related to the depth of ground water, temperature and chemical characteristics of the water (Cl^{-1} ions, EC- electrical conductivity).

The locations of wells, springs and shafts were digitized in the ArcGIS environment (Fig. 5). Attribute tables (database) have been created containing all the available hydro-geological data for each one of the digitized locations.

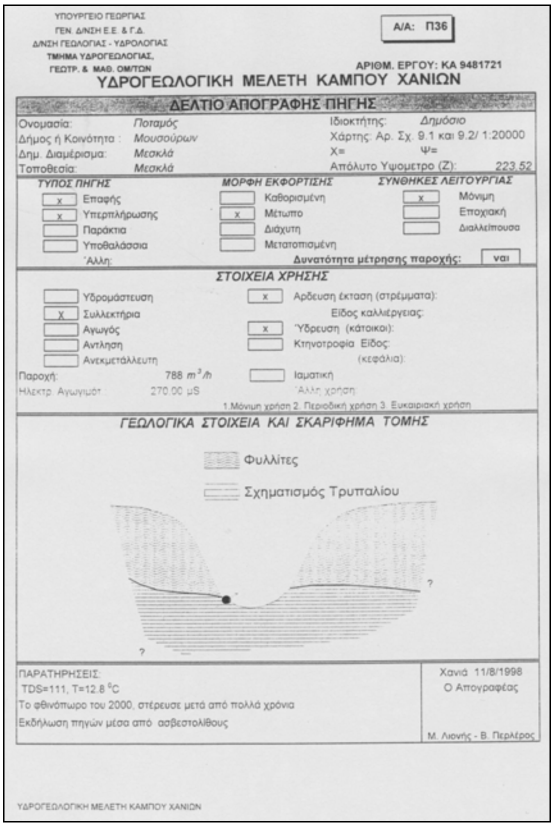


Figure 4. Card inventory of Springs.

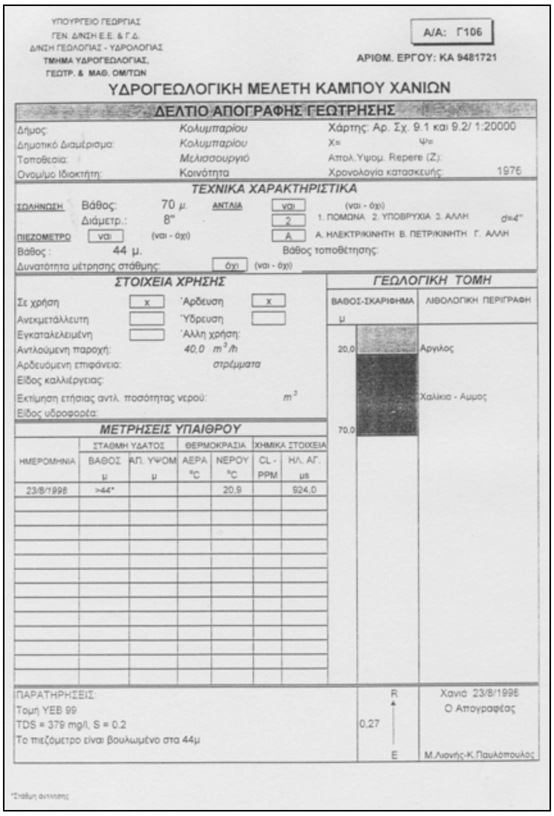


Figure 3. Card inventory of Hydrowells.

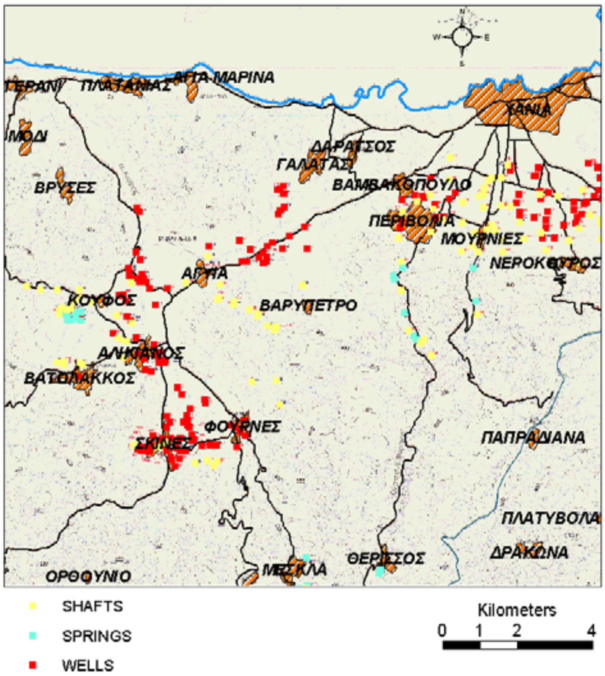
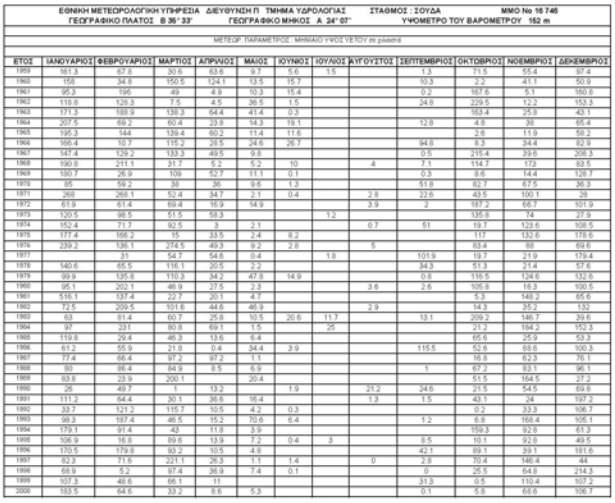


Figure 5. Detail of the digitized locations of wells, springs and shafts as well as the villages and the road network of Chania prefecture, generated from the hydrological maps of Department of Hydrology of the Ministry of Agriculture.

3.2 Meteorological Data

The use of hydro-meteorological data indicating climatic variations is essential in any kind of environmental study.

The necessary meteorological data of the Chania area catchments, such as rainfall, air temperature, relative humidity, evaporation, solar radiation, wind velocity and barometric pressure have been collected from a network of stations of the National Meteorological Service and the Department of Hydrology of the Ministry of Agriculture in the form of pdf files (Fig. 6). The aforementioned data comprise monthly values and cover a time period of 1950 to 2002.



ΕΘΝΙΚΗ ΜΕΤΕΩΡΟΛΟΓΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΕΥΘΥΝΣΗ Π ΤΜΗΜΑ ΥΔΡΟΛΟΓΙΑΣ ΣΤΑΘΜΟΣ : ΣΟΥΔΑ ΜΜΟ No 16 746

ΓΕΩΓΡΑΦΙΚΟ ΠΛΑΤΟΣ Β 35° 33' ΓΕΩΓΡΑΦΙΚΟ ΜΗΚΟΣ Α 24° 07" ΥΨΟΜΕΤΡΟ ΤΟΥ ΒΑΡΟΜΕΤΡΟΥ 152 m

ΜΕΤΕΩΡ. ΠΑΡΑΜΕΤΡΟΣ : ΜΗΝΙΑΙΟ ΥΨΟΣ ΥΕΤΟΥ σε χιλιοστά

ΕΤΟΣ	ΙΑΝΟΥΑΡΙΟΣ	ΦΕΒΡΟΥΑΡΙΟΣ	ΜΑΡΤΙΟΣ	ΑΠΡΙΛΙΟΣ	ΜΑΙΟΣ	ΙΟΥΝΙΟΣ	ΙΟΥΛΙΟΣ	ΑΥΓΟΥΣΤΟΣ	ΣΕΠΤΕΜΒΡΙΟΣ	ΟΚΤΩΒΡΙΟΣ	ΝΟΕΜΒΡΙΟΣ	ΔΕΚΕΜΒΡΙΟΣ
1959	161.3	67.8	30.6	63.6	9.7	5.6	1.5		1.3	71.5	55.4	97.4
1960	158	34.8	150.5	124.1	13.5	15.7			10.3	2.2	41.1	50.9
1961	95.3	196	49	4.9	10.3	15.4			0.2	167.6	5.1	160.8
1962	118.8	128.3	7.5	4.5	36.5	1.5			24.8	229.5	12.2	153.3
1963	171.3	188.9	138.3	64.4	41.4	0.3				163.4	25.8	43.1
1964	207.5	69.2	60.4	23.8	14.3	19.1			12.8	4.8	38	65.4
1965	195.3	144	139.4	60.2	11.4	11.6				2.6	11.9	58.2
1966	166.4	10.7	115.2	28.5	24.6	26.7			94.8	8.3	34.4	82.9
1967	147.4	129.2	133.3	49.5	9.8				0.5	215.4	39.6	208.3
1968	190.8	211.1	31.7	5.2	5.2	10		4	7.1	114.7	173	83.5
1969	180.7	26.9	109	52.7	11.1	0.1			0.3	8.6	14.4	128.7
1970	85	59.2	38	36	9.6	1.3			51.8	82.7	67.5	36.3
1971	268	268.1	52.4	34.7	2.1	0.4		2.8	22.6	43.5	100.1	28
1972	61.9	61.4	69.4	16.9	14.9			3.9	2	187.2	66.7	101.9
1973	120.5	98.5	51.5	58.3			1.2			135.8	74	27.9
1974	152.4	71.7	92.5	3	2.1			0.7	51	19.7	123.6	108.5
1975	177.4	166.2	15	33.5	2.4	8.2				117	132.6	178.6
1976	239.2	136.1	274.5	49.3	9.2	2.8		5		83.4	88	69.6
1977		31	54.7	54.6	0.4		1.8		101.9	19.7	21.9	179.4
1978	140.6	65.5	116.1	20.5	2.2				34.3	51.3	21.4	57.6
1979	99.9	135.8	110.3	34.2	47.8	14.9			0.8	116.5	124.6	132.6
1980	95.1	202.1	46.9	27.5	2.3			3.6	2.6	105.8	16.3	100.5
1981	516.1	137.4	22.7	20.1	4.7					5.3	148.2	65.6
1982	72.5	209.5	101.6	44.6	46.9			2.9		14.3	35.2	132
1983	63	81.4	60.7	25.8	10.5	20.6	11.7		13.1	209.2	146.7	39.6
1984	97	231	80.8	69.1	1.5		25			21.2	184.2	152.3
1985	119.8	29.4	46.3	13.6	6.4					65.6	25.9	53.3
1986	61.2	55.9	21.8	0.4	34.4	3.9			115.5	52.6	88.6	100.3
1987	77.4	66.4	97.2	97.2	1.1					16.8	62.3	76.1
1988	80	86.4	84.9	8.5	6.9				1	67.2	83.1	96.1
1989	83.8	23.9	200.1		20.4					51.5	164.5	27.2
1990	26	49.7	1	13.2		1.9		21.2	24.6	21.5	54.5	69.8
1991	111.2	64.4	30.1	36.6	16.4			1.3	1.5	43.1	24	197.2
1992	33.7	121.2	115.7	10.5	4.2	0.3				0.2	33.3	106.7
1993	98.3	187.4	46.5	15.2	70.6	6.4			1.2	6.8	168.4	105.1
1994	179.1	91.4	43	11.8	3.9					159.3	92.8	61.3
1995	106.9	16.8	89.6	13.9	7.2	0.4	3		8.5	10.1	92.8	49.5
1996	170.5	179.8	93.2	10.5	4.8				42.1	89.1	39.1	181.6
1997	82.3	71.6	221.1	26.3	1.1	1.4		0	2.8	70.4	146.4	44
1998	68.9	5.2	97.4	36.9	7.4	0.1			0	25.5	64.8	214.3
1999	107.3	48.6	66.1	11					31.3	0.5	110.4	107.2
2000	183.5	64.6	33.2	8.6	5.3				0.1	5.8	68.6	106.7

Figure 6. The form of the available Meteorological data.

3.3 Elevation Data

The Digital Elevation Model (DEM) of the study area with a cell size of 20 m is a continuous raster layer, in which data values represent elevation (Fig. 7). It was generated from the topographic maps (1: 20000) of the study area using the ArcGIS software (GIS package).

As a result, significant geomorphological parameters such as slope gradient have been quantified.

Furthermore, digital elevation models (DEMs) are a useful data source for the automatic delineation of flow paths (Fig. 8), sub watersheds and flow networks for hydrologic modeling [6]. Digital representation of the flow network is essential to distributed hydrologic models because it encodes the model element linkages through which flow is routed to the outlet. Although field mapping is acknowledged as the most accurate way to determine channel networks and drainage density, it is often impractical, especially for large watersheds [6]. We used the Digital Elevation Model of the study area in order to derive flow networks and perform automatic stream delineation.

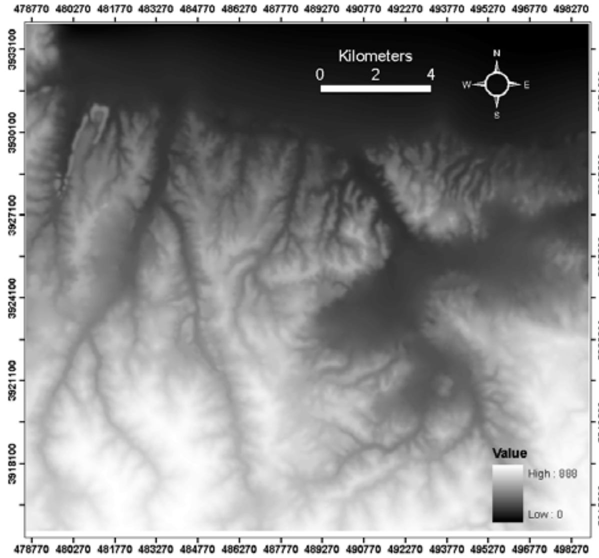


Figure 7. Digital Elevation Model of the broader Chania area.

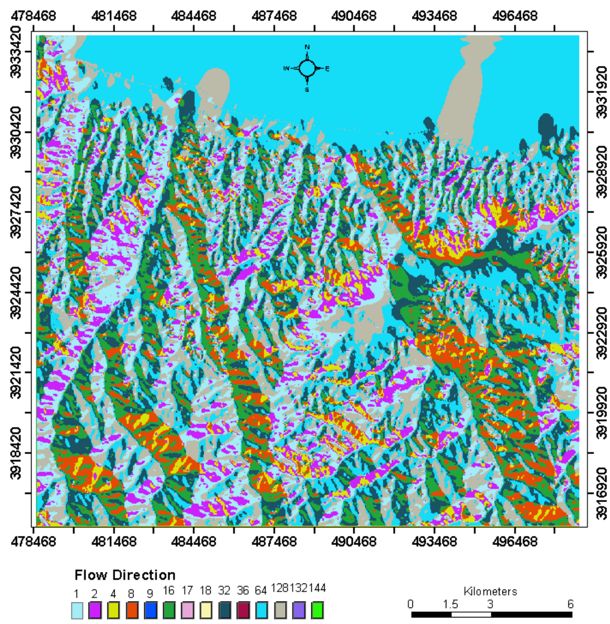


Figure 8. Flow direction map which derived from the DEM of the broader Chania area.

3.4 Geo-tectonic Data

Geological maps of the particular area have been used in combination with GIS software in order to categorize soil types and rock formations and then infiltration rates will be assigned to each geological formation based on literature and recent regional hydro-geologic surveys, so as to estimate groundwater recharge.

The tectonic faults of the study area were digitised in order to examine possible spatial relation between faults, springs and riverbed distribution.

In a further approach, a layer of the drainage network was generated using as source the hydrological maps (1:20000) of the study area (Fig. 9). Initially, this was conducted in order to evaluate the accuracy of hydrological stream networks derived from the digital elevation model (DEM).

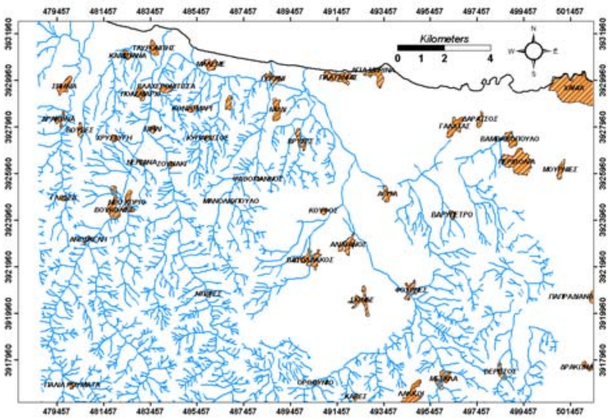


Figure 9. Detail of the digitized drainage network originated from the 1:20000 hydrological maps of the study area.

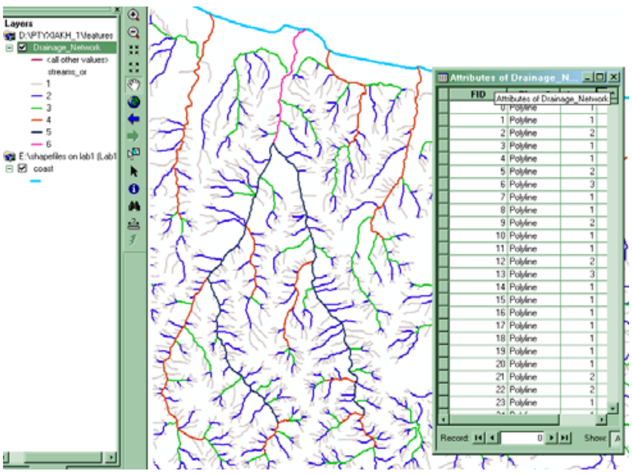


Figure 10. Detail of the ordering (according to Strahler's system) of the digitized drainage network originated from the 1:20000 hydrological maps of the study area.

The ordering of the digitized streams was further defined according to Strahler's system [7]. In this classification approach, streams with no tributaries are defined as first order; two first-order streams join to form a second-order stream. In general, two streams of the same order join to form a stream with a stream order increased by one (Fig. 10).

The results that will be obtained on the basis of stream and drainage basin analysis may provide information for an improved understanding of hydrological characteristics in the broader Chania area.

Furthermore, the integration of the geological and tectonic structures, bedrock topography, drift thickness, lithology and slope of drainage basins is going to reveal the role of geomorphological and geological factors in the evolution of streams in the Chania prefecture area.

4 Conclusions

Significant demands for students who can use geographic information system (GIS) technology have led many academic institutions to establish under-graduate courses.

One of the most effective ways of teaching process is through the problem-solving under-graduate projects which are carried out in the Department of Natural Resources & Environment of the Technological and Educational Institute of Crete, Greece. In a spatial reasoning context, which involves selecting data, extracting spatial information and analyzing that information, a special set of skills needs to be acquired in order to complete the project successfully. The multi-layered decision-making undergraduate research projects provide feedback and can teach most elements of the process.

Besides the pure educational character of the study which is described herein, our scientific effort attempts to combine state-of-the-art techniques including GIS applications and hydrologic models to develop a sustainable water management plan which will achieve both environmental protection and coverage of human water demands in the Chania prefecture area. With the extensive analysis and study of all the available scientific data both in temporal and spatial basis we intend to quantify the hydrologic regime of the Chania prefecture area. Our aim is to produce specific principles and guidelines that scientists and local authorities will adopt.

5 Acknowledgements

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