GIS – based water management in the Chania area, Western Crete

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Abstract: - The aim of this work 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 all the available hydrological data collected from the local authorities have been integrated into a GIS environment and several thematic maps have been created using as source hydrological, hydro-geological and meteorological data. This approach helped to the determination of the hydrological properties, the evaluation of the chemical characteristics of the underground water and the construction of water level and hydro-chemical maps. Moreover, the positive water balance estimation for the Tavronitis basin, a major watershed of the study area, comes in agreement with the water level observations and the existed water management scenarios of the study area.

Key-Words: - Geographic Information Systems, water management, water balance, Chania prefecture.

1 Introduction

GIS is one of the most important tools for integrating and analyzing spatial information from different sources or disciplines. It helps to integrate, analyze and represent spatial information and database of any resource, which could be easily used for planning of resource development, environmental protection and scientific investigations.

The tabular data concerning hydrological parameters of the northern area of Chania Prefecture, in Crete, were collected from the local authorities and were converted into GIS layers. Afterwards, the data were analysed as automated mapping and quantitative data analysis using GIS have been successfully applied for groundwater planning and management.

The GIS database system is used in order to help for applying groundwater management practices such as, proper groundwater resource management in terms of groundwater quality and quantity, integrated management of water, land-use of the area under investigation and the environment and to prevent groundwater quality through proper monitoring and evaluation. Hence, the groundwater chemistry could reveal important information of the suitability of groundwater for domestic, industrial and agricultural purposes. For the above mentioned reasons several hydrological thematic maps of the northern Chania Prefecture area were produced. Furthermore, the water balance for one of the two major watersheds (Keritis and Tavronitis basins) of the study area was estimated since it is an essential and crucial task for the formulation of sustainable water management scenarios of the study area.

2 Hydro-Geological Framework of the Study Area

Crete is considered as a semi-arid region [1]. 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% [1].

In Crete, water imbalance is mainly comes from the following three reasons, the temporal and spatial variations in the precipitation, the increase in water demands during summer months (tourist period) and the difficulty of transporting water due to the mountainous terrain [2].

The demand for irrigation water is high, while at the same time only 31.0% of the available agricultural land is irrigated [1]. 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.

Our study is focused on the Western part of Crete, on the area of Chania Prefecture (Fig. 1).

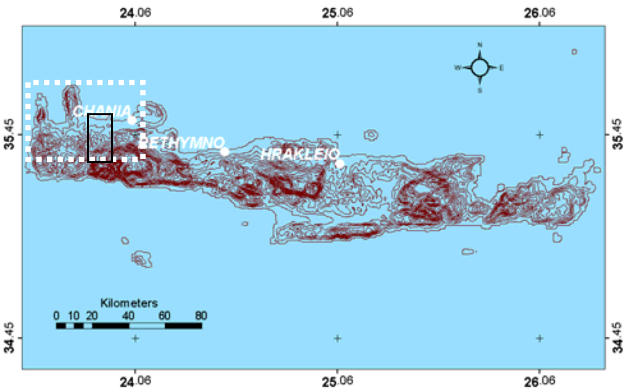


Figure 1. A map of Crete island. The study area is indicated with a dashed white square, while the Tavronitis basin is shown with the black rectangle.

In the sense of permeability the exposed geological formations of the study area can be classified into four hydro-lithological units: high permeability rocks which comprise the karstic limestones of Tripolis and Trypalion nappes, medium permeability rocks which consist of the Quaternary deposits as well as the Miocene to Pliocene conglomerates and marly limestones, low permeability rocks which consists of the Pliocene to Miocene marles and impervious rocks which consist of the phyllites – quartzites unit.

The tectonic regime of the study area is characterizing by faults of NW-SE and E-W directions. These tectonic structures clearly define the boundaries between the existing geological and hydro-lithological units.

3 Data Acquisition and Data Analysis

In order to create the appropriate information platform it was essential to collect all the available data (hydrological, geological, meteorological, and topographical).

The hydrological and hydro-geological data of the broader area of Chania (wells, springs and shafts) were collected from the Hydro-Geological study of Chania and provided from the Department of Hydrology of the Ministry of Agriculture. These data are in the form of maps and card inventories which contain important information such as the record code, the geographical coordinates of the data, the water supply, the usage and an in-situ time sequence of measurements related to the depth of ground water table, temperature and chemical characteristics of the water (TDS-Total Dissolved Solids and EC-electrical conductivity).

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.

The above mentioned digital information were analyzed aiming to examine a probable spatial relation between hydro-lithological units, faults, springs, shafts and riverbed distribution. For this purpose, several thematic maps using as source hydrological, hydro-geological and tectonic data were created.

The mapping and interpolation functions of GIS were also used for the production of maps of water quality parameters as well as water supply and groundwater levels.

Geological maps of one of the two major drainage basins of the study area, the Tavronitis drainage basin, were used in combination with GIS software in order to categorize rock formations and then infiltration rates were assigned to each geological formation based on literature and recent regional hydro-geological surveys, so as to estimate groundwater recharge. The necessary meteorological data of the Tavronitis area catchments, such as rainfall, were collected from a network of stations of the National Meteorological Service and the Department of Hydrology of the Ministry of Agriculture. The aforementioned data comprise monthly values and cover a time period of 1950 to 2002.

4 Results

Different maps have been produced mainly using point data spatial analysis of GIS. The following parameters have been selected and their respective maps have prepared believing that the analytical results would indicate the hydrological conditions of the project area.

4.1. Hydrological maps

The possible spatial relation between hydro-lithological units, faults, springs, wells, boreholes and riverbed distribution was examined with the creation of thematic maps as the one of Figure 2. In many cases, the springs, wells and boreholes distribution coincides with either major tectonic lineaments or streams. In some other cases their linear distribution indicates the probable presence of linear structures such as faults or hydro-lithological boundaries.

4.2. Water supply map

The water supply map (Fig. 3) that was produced shows maximum values inside the two major watersheds of the study area, the Tavronitis and it's tangential to the east, Keritis basin.

4.3. Water level map

As a part of the hydrologic cycle, groundwater is always in motion from regions of natural and artificial replenishment to those of natural and artificial discharge [3]. One of the main imperative approaches for the identification of groundwater flow directions is the water level contour map. Hence, water level contour map of the study area was constructed, based on water heads in meters above sea level (a.s.l.) (Fig. 4).

4.4. Water Quality Maps

The presence or absence of a potential salinity problem and the monitoring of fresh and saline water mixing is evaluated from the electrical conductivity of the irrigation water (EC) and by the Total Dissolved Solids (TDS). These two values by themselves are usually an adequate measure of a potential salinity problem (Table 1).

Conductivity can be regarded as a crude indicator of water quality for many purposes, since it is related to the sum of all ionised solutes or total dissolved solid (TDS) content. Electrical conductivity is widely used for the total dissolved solids may increase owing to the disposal of wastewater, urban runoff and increased erosion due to the land-use changes in the drainage basins [4]. In the Mediterranean environments, the high conductivities are most likely related to high evapotranspiration, evaporitic deposits and intensive agriculture.

As it can be seen from figures 5 and 6, and the Table 1, the electrical conductivity and the total dissolved solids parameters indicate salinity moderate problems for the Kissamos area (EC>1) as well as the central part of the study area (700<TDS<2000), while a small area northwest of Kissamos may suffers from severe irrigation problem (EC>3).

Table 1. Guidelines for water quality for irrigation (modified from [5], [6]).

Potential Irrigation Problem	Restriction on Use		
	No	***Slight to Moderate***	***Severe***
Total Dissolved Solids (TDS) mg/l	**<700**	**700 - 2,000**	**>2,000**
Electrical Conductivity (EC) dS/m	**<1**	**1 to 2.5**	**>3**

4.5.Water Balance Calculation for Tavronitis Watershed

Geological maps were used in combination with GIS software in order to categorize rock formations and then infiltration rates (I_1-I_n) were assigned to each geological formation based on literature and recent regional hydro-geologic surveys. The infiltration rate for each formation was multiplied with its area of extent (E_1-E_n) giving the infiltration capacity of the five geological formations (Table 2, Fig. 7) and the total infiltration capacity of the Tavronitis watershed was calculated equal to 0,0952067 (I=9,52%) with the use of equation (1):

$$I = \frac{I_1 E_1 + I_2 E_2 + ... + I_n E_n}{E_T} \quad (1)$$

Table 2. Infiltration capacity for the five formations of Tavronitis watershed.

Formations	**Infiltration(%)**
Alluvial	26
Karst-Formations	40
Quartzites - Phylites	3
Conglomerates–Marly Limestones	15
Marles	15

The necessary precipitation data were collected from a network of four adjacent stations. According to these, Tavronitis receives an annual average precipitation of the order of 120×10^6 m^3 from which the 32×10^6 m^3 (26%) corresponds to surface runoff through the mainstreams, which finally percolates through the riverbed and infiltrate the Neogene sediments. The rest 74% is considered to be the sum of evaportransipation and infiltration through the phyllites.

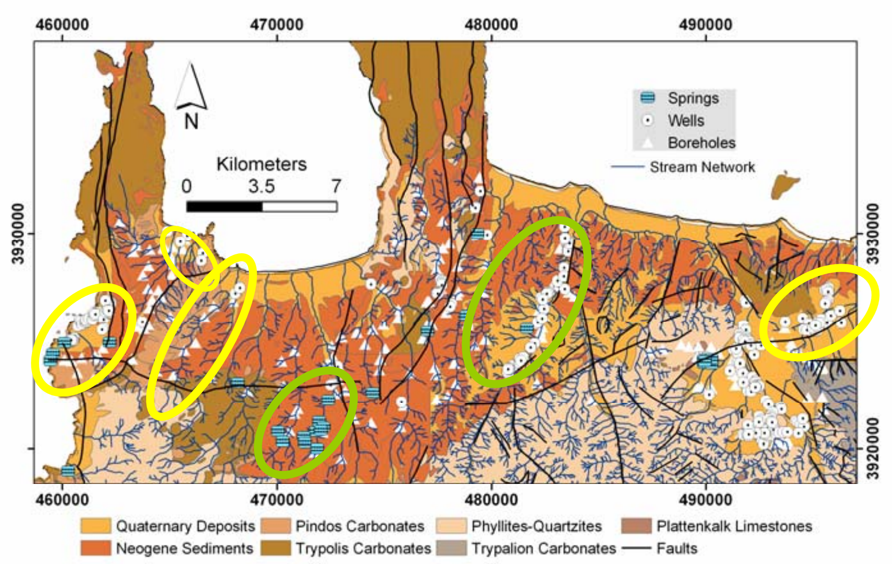
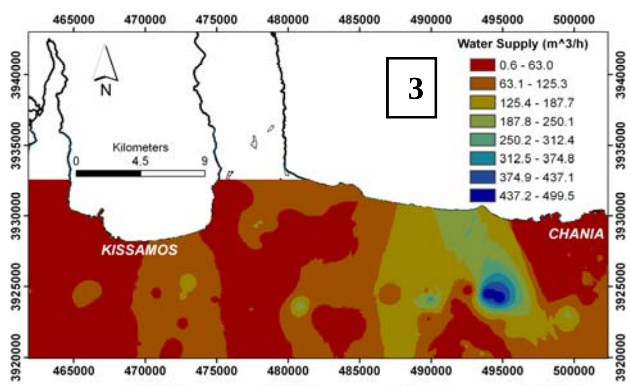
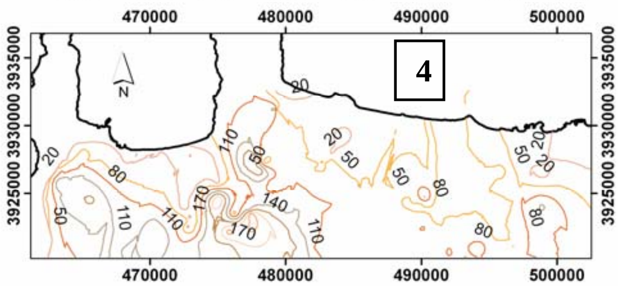
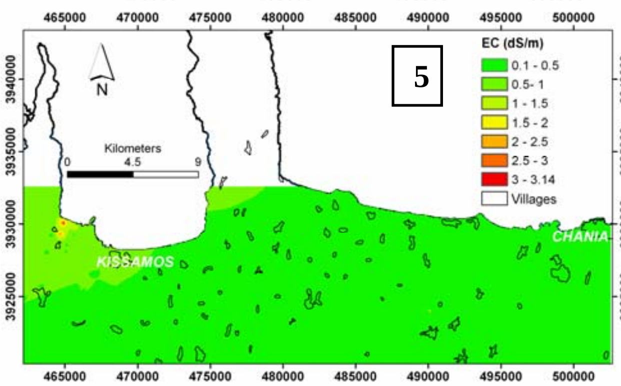


Figure 2. Spatial relation between hydro-lithological units, faults, springs, wells, boreholes and riverbed distribution. The springs, wells and boreholes distribution coincides with either major tectonic lineaments or streams (green areas) or their linear distribution indicates the probable presence of linear structures such as faults or hydro-lithological boundaries (yellow areas).







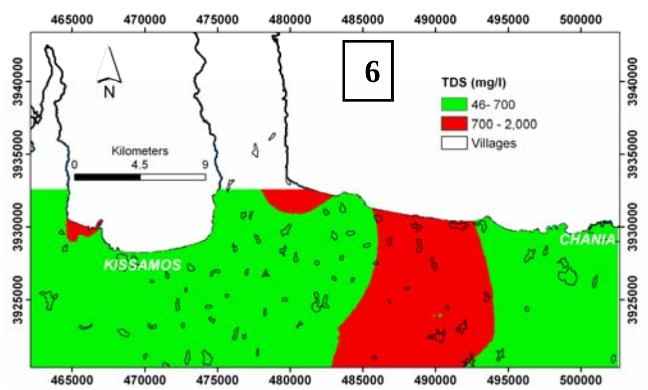


Figure 3. The water supply map shows maximum values inside the two major watersheds of the study area, the Tavronitis and it's tangential to the east, Keritis basin.

Figure 4. Water level contour map of the study area based on water heads in meters above sea level (a.s.l.).

Figures 5, 6. The electrical conductivity (EC) and the total dissolved solids (TDS) parameters indicate salinity moderate problems for the Kissamos area (EC>1) as well as the central part of the study area (700<TDS<2000), while a small area northwest of Kissamos may suffers from severe irrigation problem (EC>3).

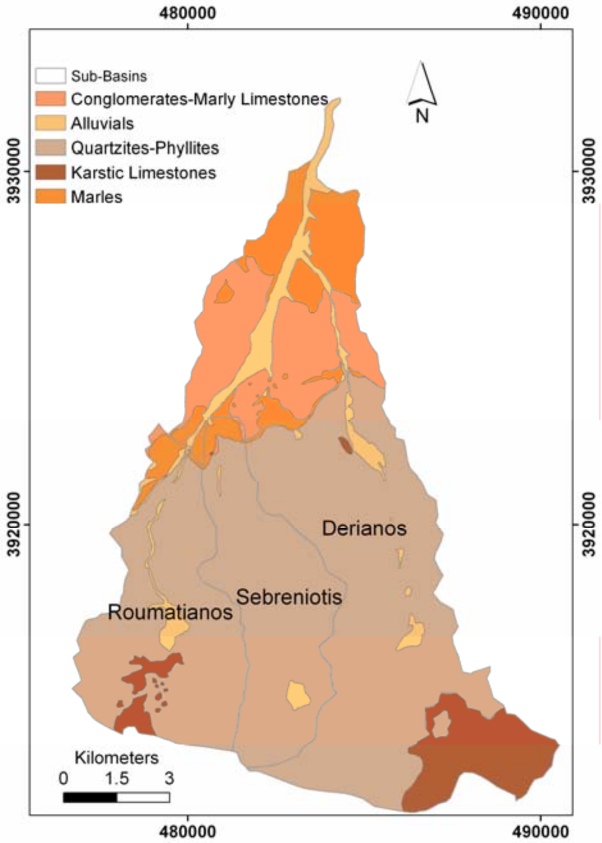


Figure 7. Geological map of the Tavronitis watershed. The three watershed sub-basins are also shown.

According to the data of IGME (Institute of Geology & Mineralogy of Greece), the annual average surface runoff volume is of the order of $27*10^6 m^3$, the percolated volume is 3.7×10^6 m^3 while the infiltrated volume is $1.2*10^6 m^3$. Thus, the total annual average underground feeding is approximately $5*10^{6} m^3$.

The above-mentioned data coupled with the calculated infiltration capacity were used for the estimation of water balance, using the equation (2):

$$P = I + R + E \qquad (2)$$

$$120\times10^6 = 11.42\times10^6 + 26.9\times10^6 + 81.68\times10^6$$

where P: precipitation (m^3), I: infiltration (m^3), R: runoff (m^3) and E: evaportranspiration (m^3).

5 Conclusions

In this work GIS applications were combined with 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.

The derived maps reveal spatial relation between hydro-lithological units, faults, springs, wells, boreholes and riverbed distribution. With the extensive analysis and study of all the available hydrological data both in temporal and spatial basis we constructed water supply, water quality and groundwater level maps.

The electrical conductivity and the total dissolved solids maps indicate salinity moderate problems for the Kissamos area (EC>1) as well as the central part of the study area (700<TDS<2000), while a small area northwest of Kissamos may suffers from severe irrigation problem (EC>3).

The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought) [7]. The higher the EC, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire "pure" water, usable plant water in the soil solution decreases dramatically as EC increases [7].

The total dissolved solids may increase owing to the disposal of wastewater, urban runoff and increased erosion due to the land-use changes in the drainage basins [4]. In the Mediterranean environments, the high conductivities are most likely related to high evaportranspiration, evaporitic deposits and intensive agriculture as well as to the proximity from major saline-water bodies.

Furthermore, from the positive estimation of water balance for the Tavronitis watershed is inferred the potential of water-bodies development.

In the future, the local authorities plan the construction of two reservoirs in the area of Roumatianos and Sebreniotis sub-basins. The two reservoirs will trap the 50% of the total Tavronitis watershed runoff. The rest 50 % seems to be an adequate quantity for the conservation of the hydro-geological regime.

Finally, all the above-mentioned information can be utilized by many categories of users, such as scientists, engineers, professionals and public employees in order to develop a sustainable water management plan which will achieve both environmental protection and coverage of human water demands in the Chania prefecture area.

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