PUMPING RATE VARIATIONS IN WELL LOCATED IN KAINA-VAMOS AREA (CRETE) AND THEIR IMPACTS ON GROUNDWATER QUALITY.

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ABSTRACT

A study based on the effect of pumping rate on both water quality and seawater intrusion was conducted in the hydrological basin of Kaina's well. Water samples from the well in Kaina-Vamos were collected from June 2003 to January 2006. Turbidity, pH, EC, BOD, COD, TOC, hardness, chloride concentration, and the colonies of *E coli*, *total coliforms* and *Fecal streptococci* were measured. The results showed concurrent increase of EC and chloride ions concentration possibly due to seawater intrusion caused by the continuous water pumping. The measured values of all chemical and microbiological qualitative parameters were below the limits of the current national regulations indicating the absence of pollution or contamination agent in the hydrological basin.

1. INTRODUCTION

The exploitation and management of groundwater in coastal aquifers are directly connected to the seawater intrusion in the aquifer which can be permanent or more commonly not permanent flow resulting in salinity rise. The salinity of aquifer waters in coastal regions is due to primary and secondary factors. The primary factors are related to the change of the natural enrichment of aquifers and are usually correlated to the transitory alleviation of the water quantities that inflow in the aquifer and it is about a periodical saltiness related to the rainfalls. The secondary factors are those that are connected with the excessive pumping. Such phenomena are usual in Greece; mainly in intensively cultivated or touristic coastal areas were free and pressurized groundwater [3].

When the rate of water pumping near the coast exceeds the rhythm of natural or artificial recharge of the aquifer, then sea water pours into the aquifer destroying the groundwater from being source of potable water. It should be stressed that this phenomenon is considered irreversible, therefore good planning and management are required to prevent it [2,6].

In most cases, the problem of seawater intrusion is easily recognized by the authorised personnel however, the extent of problem is unknown. Additionally the problem can reach impermissible limits when the suitable measures are not taken in time.

Kaina is one to several coastal regions in Greece, where intensive salt water intrusion in the aquifer occurs possibly due to anthropogenic causes. The overexploitation together with the absence of any integrated water resources management plan has resulted in the degradation of the groundwater quality. The aim of the present research was to correlate the pumping rate of Kaina's well to the physical, chemical and microbiological characteristics of the groundwater as a source of potable water.

2. MATERIALS – METHODS

The well of Kaina is located at the central part of the Municipality of Vamos in the north-eastern part of Chania Prefecture and it began to function in 1998 to cover needs of water supply for the Municipality [5]. It is found roughly 6 km south of the northern coast of Crete. The depth of the free water table is located at a depth of 209m applying piezometric measurements. The head of the borehole is 10m above sea level.

The broader area of Kaina village is composed mainly of karst water-bearing carbonate rocks (Plattenkalk limestones and Trypolis carbonates). The Jurassic carbonates overlying Permian Plattenkalk Limestones as is shown in figure 1. The southern part of Kaina is composed of Neogene sediments while Quaternary deposits are present in the northern part if the area under investigatioin (Fig. 1) Based on orientation, two kinds of discontinuities or fractures can be observed, aligned approximately along NNW-SSE and almost W-E directions. These tectonic discontinuity features are also responsible for the appearance of the groundwater in the area and control the flow and the quality of the water resources.

The annual rainfall in the Municipality of Vamos varies between 360-1100mm with an average of 700mm during the last 30 years. All rainfalls occurs from October to March. The sampling period of 2003-2006 includes the wet years 2002-2003 with 1100mm rainfall and the dry years of 2003-2006 with 590 and 360mm rainfalls respectively (Fig 2).

Groundwater samples from the well of Kaina were obtained from July 2003 through to January 2006. Water samples were collected in 2lt plastic polyethylene bottles, placed in a portable cooler and transported in the Laboratory of Water & Soil Resources Quality Control, where all samples were analysed within 6 hours of collection. From June 2004 up to January 2006 a flow meter was installed recording the volume of water pumped.

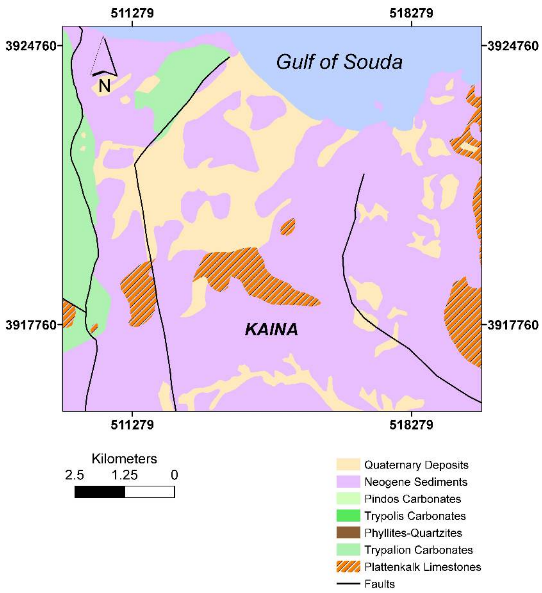

Figure 1. Geological map of the broader area of Kaina village. The major tectonic features of the area are shown with black lines.

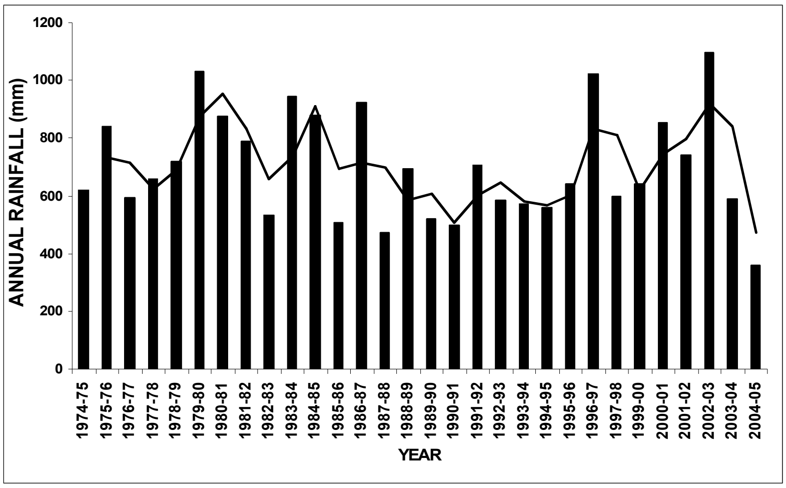

Figure 2. Annual rainfall the period from 1974 to 2005 in the Municipality of Vamos (Data from the Dept of Water Resources Management). Line represents the rainfall moving average.

For the analysis of the qualitative parameters turbidity, pH, EC, BOD, COD, TOC, hardness, chloride concentration, as well as for the bacterial detection official methods were employed [1]. The turbidity levels were determined in the laboratory by using a portable turbidity meter (Lovibond CR 3210) and the results were expressed in Nephelometric Turbidity Units, (NTU). The physicochemical parameters of pH and electric conductivity were measured by a HACH (sension 156) instrument equipped with the respective electrodes. The concentration of the Biochemical Oxygen Demand (BOD_5) was measured manometrically with special BOD device (Lovibond), which was provided with bottles equipped with digital sensors.

The concentration of Chemical Oxygen Demand (COD) was measured with Cell Test (MERCK 14560, with analysis range 4-40mg/lt COD) and detected with photometer (MERCK Spectroquant NOVA 60). A total Organic Carbon analyzer (Shimatzu TOC-B) was used for the measurement of TOC in the water samples, whereas the chloride (Cl^-) concentration was determined according to the Mohr method.

Water samples of 100ml were filtered through sterile 47mm/0.45pore size cellulose filters (Pall-Gelman Sciences GN 66191) which were placed on Membrane Lauryl Sulphate Broth substrate (Lab 082-LAB M) in petri dish. Incubation at 37^{o}C or 44^{o}C for *total coliforms* or *E. coli,* respectively, for 24hrs was followed. For the presence of *Fecal streptococci*, all water samples were filtered, placed on Slanetz and Bartley Agar substrate (LabM 166 - LAB M) in petri dish and were incubated at 35^{o}C for 48hrs.

3. RESULTS-DISCUSSION

Coastal well systems have to be safe guarded to prevent them from salinisation. Monitoring the quality of groundwater on a regular basis is important in coastal areas where salt water intrusion may be expected [4]. The well in Kaina began to function on 1998 supplying the municipal water network and covering mainly domestic needs during the summer period. However no data were recorded on pumping rate and water quality. Since the beginning of the pumping period, this is the first systematic study of Kaina's well which evaluates data of conductivity and chloride concentration in water samples and correlates them to the pumping capacity of the groundwater table and the seawater intrusion rate.

Water samples analysis showed constant values of pH (7.2-7.8) while turbidity range between 3.0 and 5.5NTU during the studied period. The results of BOD_5 (0-3mg/l), COD (4-6mg/l) and TOC (0-0,35mg/l) analyses during the studied period, didn't show any human pollution of the ground water (Table 1). In addition, the null findings in the microbiological analysis of bacteriological indicators such as *total coliforms*, *E. coli,* and *Fecal streptococci* (Table 1) showed no evidence for fecal pollution of the hydrological horizon.

Table 1. Physicochemical, chemical and microbiological analyses of water samples of Kaina's well.

Date	30/07/03	18/08/03	12/09/03	30/10/03	01/12/03	09/06/04	06/07/04	27/07/04	17/08/04	16/09/04	15/10/04	12/11/04	14/12/04	17/02/05	06/04/05	18/05/05	04/07/05	09/09/05	12/01/06
ph	7,4	7,8	7,7	7,6	7,68	7,6	7,71	7,8	7,5	7,3	7,39	7,2	7,5	7,8	7,6	7,59	7,4	7,78	7,4
BOD_5 (mg/l)	0	0	1	0	1	0	3	2	0	0	0	0	0	1		0	0		
COD (mg/l)						3,8	3,5	4,8	3,5	3,5	6	6	6	3	6	4,6	5	4	4
TOC (mg/l)						0,06	0,02	-	0,2	0,1	0,35	0,2	0	-	-	0,02	-	0,16	0,1
Turbidity (NTU)	1	1,5		1,9		4,4	3,5	1,6	3,5	0,8	3,6	-	3,6	5,5	3,8	3	1,6	1	5
Total colif. (cfu/100ml)	0	0	0	0	0	0	0	2	2	0	0	0	0	1	3	0	1	0	0
E Coli (cfu/100ml)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fecal streptococci (cfu/100ml)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The data of the period 2003-06 showed that the increase of chloride concentration was followed by an increase in electrical conductivity (Figs. 2A and 2B). This is the main risk for the groundwater of the well. Water conductivity was low throughout the summer period of 2003 ranging from 470 to 560μS/cm, while Cl^- concentration did not exceed 60mg/l. This is due to the heavy rainfall of the 2002-03 period (1100mm annual precipitation) which resulted in the aquifer being adequately recharged. The increased pumping rate (1000-1200 m^3/day) during the summer of 2004 caused the progressive rise of conductivity at 1170μS/cm and the increase of Cl^- concentration from 130 to 230mg/l. Next winter's rainfalls (2004-05) were dramatically reduced by 67% (360mm) resulting in a lower inflow and recharge rate of the well. The water conductivity was then measured at 900μS/cm. Over pumping rate during the summer of 2005 aggravated water quality of the well, as conductivity exceeded 1800μS/cm and Cl^- concentration reached at 370mg/l (Figs. 2A and 2B). The extent of seawater intrusion is indicated by the increase of both EC and Cl^- concentration which were found in a linear dependence with a correlation coefficient of R^2=0,964 (Fig. 3).

Worldwide excessive pumping of coastal aquifers is the most important anthropogenic cause of salt water intrusion since saline groundwater is nearby and saline groundwater upconing can easily occur [4]. The salination of the groundwater well system can lead to a severe deterioration of the existing fresh water resources. The critical condition of Kaina's well is obvious when the measured values of the qualitative parameters are compared to the limits of the national regulations for potable water, which range between 400-2500μS/cm and 25-200mg/l for conductivity and Cl^- concentration, respectively. The deterioration of water quality measured by electric conductivity and chlorides during the water over-exploitation period coincide with the highest pumping rate (Fig. 2C) demonstrating a cause/response influence.

The cumulative pumping of 150.000m^3 and 200.000m^3 of water during the summer periods of 2004 and 2005 (Fig. 2D), respectively, substantially exceeded water pumping capacity and negatively affected the groundwater table. The observed risk of seawater intrusion and the lack of resistance of the well demonstrate the limitation of Kaina's well current pumping capacity, particularly after a dry winter. The operation of the well should always obey the rules of sustainable management of the water resources in order to allow the normal function of the recharge mechanism of the aquifer preventing the salt water intrusion [2,4,6].

It takes time before the salination of aquifers due to the negative effect of human activities, such as over pumping, is actually observed. The main reason is that in the salination process enormous volumes or fresh groundwater have to be replaced by saline groundwater. As such, countermeasures to compensate for the salinisation process should be taken in time, since the time lag is considerable (decades to centuries) before these measures result in effective changes in the salinity distribution of the aquifer [2]. In Kaina's well the following technical countermeasures to prevent or retard the salination process can be considered i) reduction of withdrawal rates and ii) increase of the recharge to enlarge the inflow of fresh groundwater in the aquifer. Moreover, to achieve sustainable management of the fresh groundwater resources in this coastal region, an intensive cooperation between authorities and water users is required. Monitoring of the salinisation process is reasonable when technical countermeasures are planned. The study will continue to monitor the water quality parameters combined with geophysical exploration techniques for the better understanding of the salination process and the water balance in Kaina's aquifer so that the authorities will be able to decide on the countermeasures that should be taken.

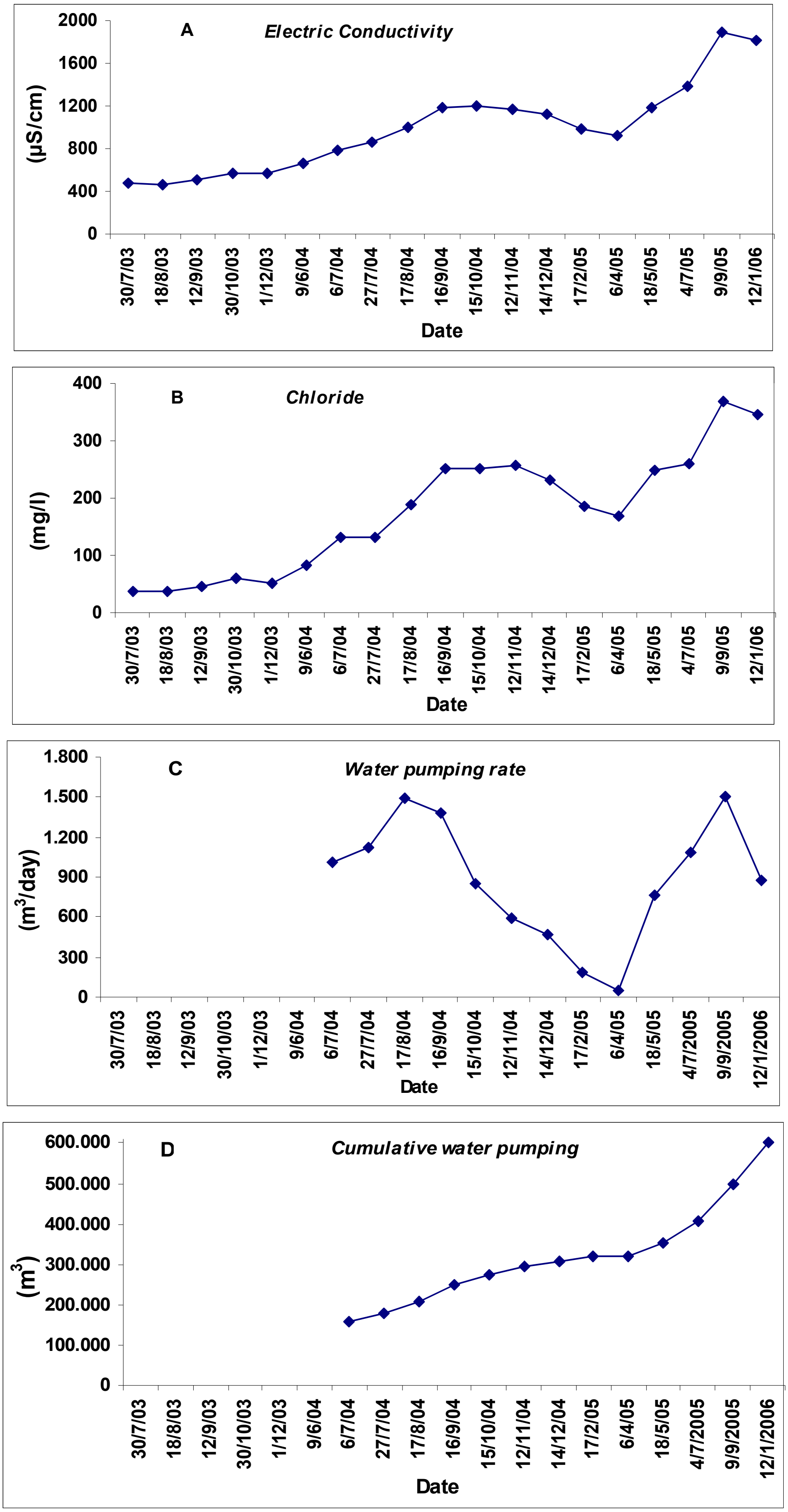

Figure 3. Monitoring of: (A) electrical conductivity (µS/cm) and (B) chloride concentration (mg/l) in water samples, (C) water pumping rate (m^3/day) and (D) cumulative water pumping (m^3) of Kaina's well.

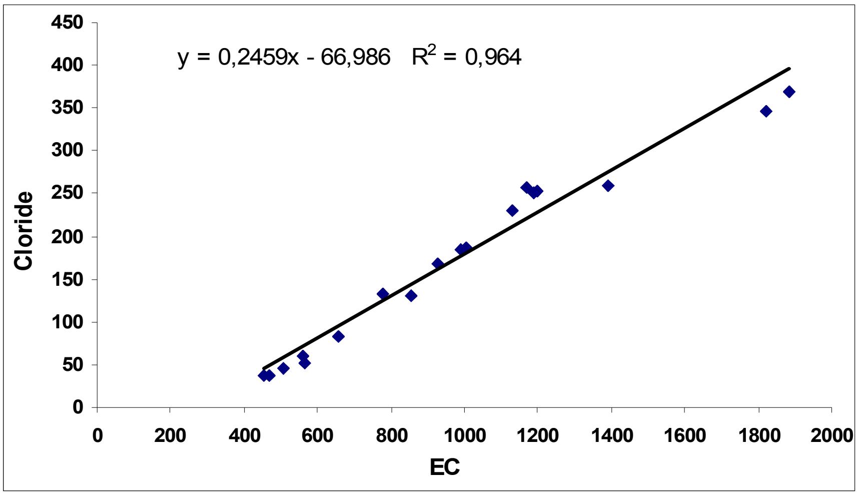

Figure 4. Correlation curve between Electrical Conductivity and Chloride Concentration for water samples of Kaina's well the period from 30/07/2003 to 12/01/2006 .

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