Global NEST Journal, Vol 7, No 3, pp 340-353, 2005

WATER RESOURCES AND GROUNDWATER QUALITY IN NORTH PELOPONNESUS (GREECE)

K.S. VOUDOURIS[1]*
P. DASKALAKI[2]
A. ANTONAKOS[3]

[1]*Lab. of Engineering Geology & Hydrogeology*
Dept. of Geology
Aristotle University of Thessaloniki.
54124, Thessaloniki, Greece
[2]*Cohesion Fund Management and Monitoring Special*
Service, Ministry of Economy and Finance
10 Nikis Str., Athens, Greece
[3]*Lab. of Hydrogeology, University of Patras*
261 10, Rio, Patras, Greece

**to whom all correspondence should be addressed*
Tel: +(30)2310-998041; Fax: +(30)2310-998530
e-mail: kvoudour@geo.auth.gr

Received: 08/11/04
Accepted: 20/03/05

ABSTRACT

Groundwater plays an important role for urban and agricultural water supply in northern part of Peloponnesus. Despite increasing environmental awareness in this area, groundwater is a resource that is being stressed. Groundwater provides about 80% the total quantity of water supply. Distribution of water resources is nonhomogeneous in this region. In general the eastern part is semiarid, whereas the western part is supplied with abundant water. Surface water potential in North Peloponnesus estimated to be 0.9-1.2x10^9 m^3 y^{-1}. Overexploitation of groundwater and the extensive agriculture has created environmental problems in some aquifers (sea water intrusion, nitrate pollution). Seawater intrusion occurs in some coastal aquifers, where negative water balance has been established. High percentage of the examined samples exceeded the maximum admissible nitrate concentration of 50 mg l^{-1}, set by EU for drinking water. Groundwater in urban areas has been contaminated to varying degrees. The water quality is classified into Ca-HCO_3 type (fresh water) and Na-HCO_3 or Na-Cl type (brackish waters) in the coastal part, due to seawater intrusion. Some recommendations are made in order to safeguard high water quality and to develop new ways of providing water source in the study area. Moreover, an integrated and comprehensive management scheme should be applied, aiming at sustainability of water resources and based on surface water and groundwater exploitation, simultaneously.

KEYWORDS: Water resources, groundwater development, groundwater quality, pollution, North Peloponnesus, Greece

1. INTRODUCTION

The northern part of the Peloponnesus, in South Greece including the Achaia and Korinthia prefecture, has an extent of 6,000 km^2 and a population of about 477,400 (census 2001). Between the 1970's and 2000's the population grew quickly, increasing by 35% (Table 1). The population density in the coastal areas is 200 persons per km^2 and it decreases to 15 persons per km^2 in the mountainous area.

The total crops area is 1311 km^2 and in a large part 550 km^2 (42%) irrigated agriculture is practiced during the last decades (Table 2). The land is mainly used for the cultivation of citrus fruits, olives, apricots and vineyards especially in the lowlands. The percentage of the irrigation area has increased between 1971-2001 from 25.5 to 41% (Korinthia) and from 21.8 to 42% (Achaia). The aforementioned percentage is one of the higher in Greece.

Table 1. Population in the studied area

Year/Prefecture	**1961**	**1971**	**1981**	**1991**	**2001**
Achaia	240,201	240,854	275,193	300,078	322,789
Korinthia	112,505	113,115	123,042	141,823	154,624
Total	352,706	353,969	398,235	441,901	477,413

Table 2. Total crops and irrigated areas in stremmas

Year	**Korinthia prefecture** Total crops-irrigated areas	**Achaia prefecture** Total crops-irrigated areas
1971	583,990-149,085 (25.5%)	707,027-154,475 (21.8%)
1991	544,789-167,071 (30.7%)	615,428-188,260 (30.6%)
1998	622,679-253,807 (40.8%)	709,242-285,412 (40.2%)
2001	625,906-256,485 (41.0%)	685,581-292,748 (42.0%)

The coastal part of the study area can be characterized as an agrotourism center in the sense of an agriculturally streamlined and tourism developed area that bounds a well-structured and densely populated urban environment (Kassimis, 1998). Water scarcity is recognized as an increasing problem and has became a vital problem for socioeconomic development of coastal part of the studied area. Water demands have continuously increased over the last 25 years in response to population growth due to rapid urbanization and agricultural activities.

The water supply is mainly covered by groundwater abstracted from the alluvial coastal aquifers via numerous wells and boreholes. The number of wells and boreholes has reached 8,000 in Korinthia prefecture (Voudouris, 1995, Panagopoulos *et al*., 2002). As a result a decline of ground water levels has been observed, since 1980's due to overexploitation of agricultural and municipal water intakes in coastal part of the study area combined with prolonged drought periods (Lambrakis *et al*., 1997). Furthermore a negative water balance is established in the coastal aquifer systems. In these systems seawater intrusion is recorded due to over-pumping combined with prolonged dry periods. An increase in the dissolved components in the groundwater, especially chloride and sodium, has been observed in many boreholes drilled into aquifers, along the coastline of the study area (Daskalaki *et al*., 1998).

Nitrate pollution is the second major source of groundwater degradation in the study area. Nitrate is a common contaminant identified in groundwater of the study area, due to the irrational application of fertilizers. The common fertilizer applied throughout the irrigation area is $(NH_4)_2SO_4$, phosphate and potash. Under a nitrification process in the presence of oxygen, ammonium is transformed into nitrate (Freeze and Cherry, 1979). The high levels of nitrate are probably the result of the lack of sewage systems in some urban areas. The main pollution source of surface water results from uncontrolled direct disposal of raw olive mill waste effluent into the torrents and rivers (Voudouris *et al*., 2000).

The aim of this study is to describe the hydrogeological regime in Northern Peloponnesus, the existing water resources management policy and the implications it has on groundwater quality. The study was carried out on the basis of an attempt to establish a policy for the sustainable development and management of water resources.

2. THE STUDY AREA

2.1 Morphology

The study area is surrounded by sea in northern part and can be considered as a mountainous area (mountains: Helmos 2355 m, Killini 2376 m, Erimanthos 2224 m, Panachaiko 1926 m).

A number of torrents/rivers run across the studied region (Figure 1) namely: Piros, Glafkos, Charadros, Volineos, Finikas, Selinountas, Vouraikos, Meganitis, Kerinitis, Krathis, Fonisa, Sithas, Asopos, Zapantis and Xirias. All of them discharge into Korinthiakos Gulf except Piros, Glafkos and Charadros, which discharge into the Patraikos Gulf. The mountainous areas are the sources of the surface water runoff and the lowlands are its discharge areas. Thus, the torrents/rivers play a mayor role to the recharge of the coastal aquifer systems.

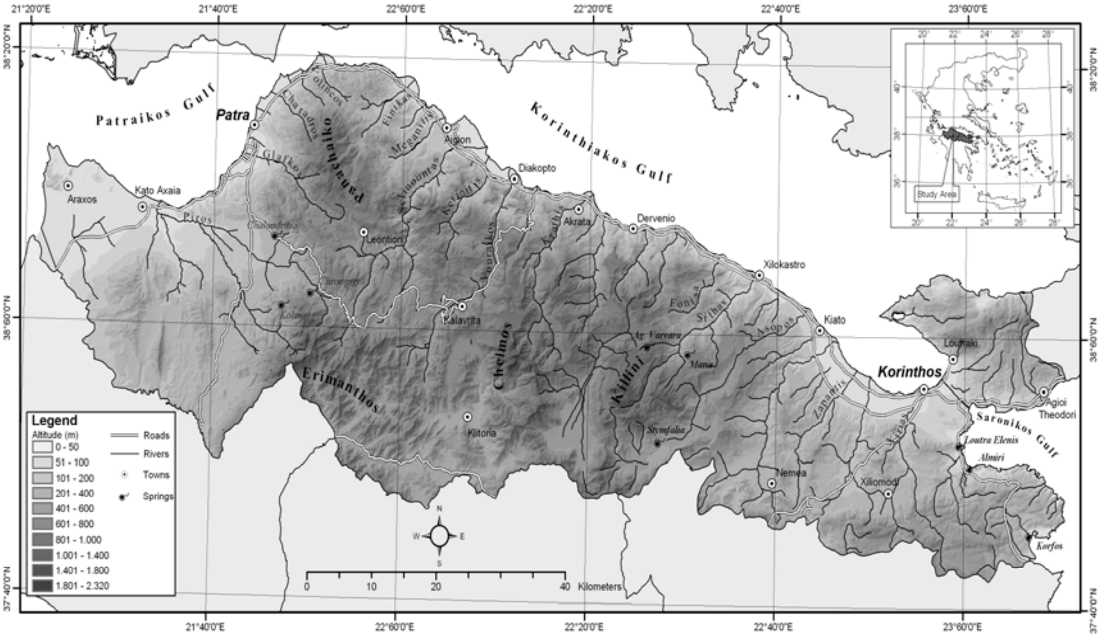

Figure 1. Location map of the study area, showing geographical features

The Asopos river flow constitutes the basic source of irrigation water in the eastern part of the study area and is being managed via a diversion dam followed by a dense network of lined canals. The mean annual runoff in each torrent/river basin, as suggested by Koukis *et al*. (1996) and Voudouris *et al*. (1997) is presented in Table 3. Hence, is a very large surface water potential in North Peloponnesus estimated to be 0.9-1.2x10^9 m^3 y^{-1}.

Table 3. Mean annual runoff of torrent/river basins in North Peloponnesus

Torrent/River	**Catchment surface area (km^2)**	**Mean annual flow (x10^6 m^3)**
Piros	506	115.6
Glafkos	118.1	32.1
Charadros	23.8	7.4
Volineos	26.4	7.2
Finikas	100.6	25.7
Selinountas	285	73.0
Vouraikos	183	116.0
Meganitis	60.1	26.0
Kerinitis	80	35.0
Krathis	166	68.0
Fonisa	54	27.0
Sithas	180	18.4
Asopos	284	50.0
Zapantis	140	7.5
Xirias	174	3.8

Table 4. Simplified geological sequence in north Peloponnesus

Geological Period	Location	Description
Quaternary	Northern part (coastal areas or inland basins)	Unconsolidated sediments sands, pebbles, breccias and fine clay to silty sand deposits
Plio-Pleistocene	Semi-mountainous area	Coarse grained (conglomerates) Fine grained (marls)
Alpine formations	Southern part mountainous area	Flysch, limestones, dolomites semi-metamorphic formations

In the Stimfalia basin (Korinthia prefecture) there is the homonymous shallow lake, which is one of the Greece's mountain lakes, covering an area of 750 hectares. The lake is recharged from the karstic springs and a considerable fraction of surface runoff is augmenting lowland irrigation networks via Asopos river (Voudouris *et al*., 2002b).

2.2 Climate

The climate of North Peloponnesus is Mediterranean of hot, dry summers and mild, wet winters. In western part is wet and in eastern part dry. There is a systematic variation in the distribution of rainfall in the area due to oreographic influence of the mountains. Based on data from 37 raingage stations, the precipitation is correlated strongest with the altitude and increases by 40 mm per 100 m. The 30-year average of rainfall at sea level is 710 mm in western part (Patras raingage) and 400 mm in eastern part (Korinthos raingage). The results from regression analysis (Voudouris, 1999) show a decrease of 3.26 mm km^{-1} of movement Eastward and a decrease of 1.2 mm km^{-1} for movement Northward. Rainfall is seasonal occurring in the wet period October-April (83% of the annual precipitation).

Average annual temperature range from 18 ^{o}C at mean sea level and decreases by 0.59 ^{o}C per 100 m of ground elevation; daytime summer temperatures are above 30 ^{o}C in the coastal areas (Voudouris *et al*, 2002a). Annual potential evapotranspiration exceeds rainfall at all the stations. The coefficient of real evapotranspiration ranges from 78% of the annual precipitation (in lowland) to 45% (in highland). Direct recharge of precipitation to groundwater takes place in wet period (November-March). The percentage of rainfall which infiltrates through the soil has been estimated to be 50% of the annual precipitation in the carbonate areas, 20% in the alluvial areas and 3-5% in low permeability areas (flysch, phyllites, fine grained neogene deposits).

An increased number of droughts (1977, 1989-91, 2000), as well floods (1997) have occurred during the last three decades (Voudouris *et al*, 2002a). Lambrakis *et al*. (1997) and Voudouris *et al*. (2002a) concluded that the annual precipitation depth in raingage stations from the study area, displays a decreasing trend over the last 50 years.

2.3 Geology

According to Voudouris (1995), Nikolaou *et al*. (1997), the following geological formations can be identified (Table 3):

- Quaternary deposits consisting of alternations of sands and fine coarse or mixed facies. The plain, north of the national highway Patras-Korinthos, is formed of recent unconsolidated material consisting of sands, pebbles, breccias and fine clay to silty sand deposits. Lateral continuity of afore described deposits is disrupted by recent and older fluvio-torrential deposits originating from the streams-rivers that flow across the studied region, as illustrated in the geological map of Figure 2. The thickness of the plain's deposits varies from 30 m to 70 m, whilst along the fluvio-torrential deposits of the rivers it exceeds 100 m. As a result of their origin the deposits are characterized by high degree of heterogeneity and anisotropy.

- Plio-Pleistocene deposits. They form the semi-mountainous region covering a large area South of the national highway Korinthos-Patras and they consist of two formations; a) the coarse grained of alpine origin conglomerates cemented by calcareous clay, b) the fine grained, of marl, clay and sand, characterized by heterogeneity in the horizontal and vertical evolution. The Lower Pleistocene uplift and subsidence movements have contributed to the formation of the Tyrrhenian marine terraces in eastern part. A number of springs develop along the unconformity between the conglomerates and the fine grained formation. The Upper Pliocene conglomerates in Nemea and Stimfalis area have a thickness of over 300 m, consisting of pebbles and cobbles cemented together with clay and fine sand.

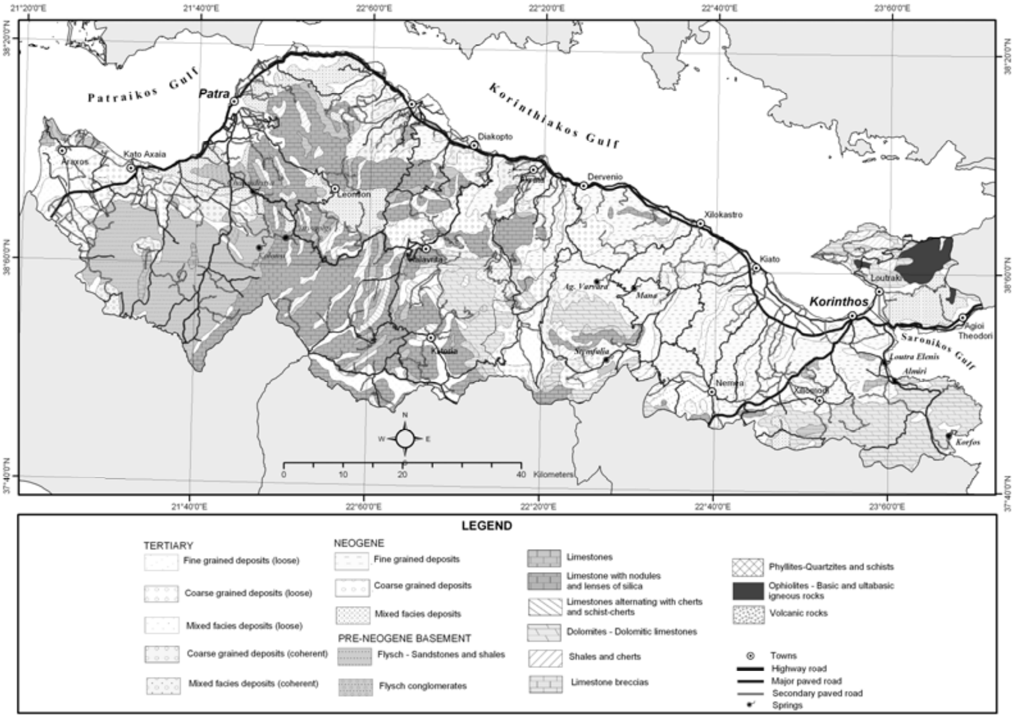

Figure 2. Geological map of the North Peloponnesus

- The Alpine formations which comprise part of the following Hellinides zones; a) Flysch and limestones of the Ionian zone, b) Flysch and limestones of the Tripolis zone, c) Limestones with chert intercalations and flysch of the Olonos-Pindos zone, d) Limestone and dolomite of Pelagonic zone, e) Semi-metamorphic formations (phyllites, siltstones, sandstones and limestones), f) volcanic rocks, g) ophiolite complex and h) palaeozoic limestones of very small extension.

The limestones of the Pindos and Tripolis zone are characterized by the presence of a joint system, which favors infiltration of rainfall and karstification.

2.4 Aquifers

The complicated geological structure of the study area results in complex hydrogeological conditions. Distribution of groundwater is nonhomogeneous in the region. The main aquifers in the area are of three types:

1. Aquifers of alluvial deposits

Alluvial aquifers are hosted in coastal areas and inland basins, supplying large quantities of water. The groundwater in the alluvium consists of phreatic and confined groundwater. The water table elevation is highest in April and lowest in October. Groundwater use on the coastal part exceeds natural recharge in dry period, and water levels decline to an extent that depends on the difference between abstraction and recharge. The hydrograph shows various water level fluctuations and that the water level declined during the dry periods (Fig. 3). In recent years many borehole fields have been established in the coastal area. Overexploitation causes a negative water balance in the many coastal aquifer systems, triggering saline water intrusion, which has negative consequences for the socioeconomic development of the area (Stamatis and Voudouris, 2003).

The beginning of the decline of the groundwater level in the coastal alluvial aquifer of Glafkos basin coincides with the increase of groundwater extraction by the Patras municipality (1984-1986) and the beginning of the drought periods (1989-1991). An increase of groundwater level was recorded in the aforementioned aquifer during the period 1994-2001 (Fig. 4). In this period the total amount of groundwater extracted for domestic and industrial purposes decreased, due to quality deterioration and deindustrialization, respectively (Mandilaras *et al*., 1999).

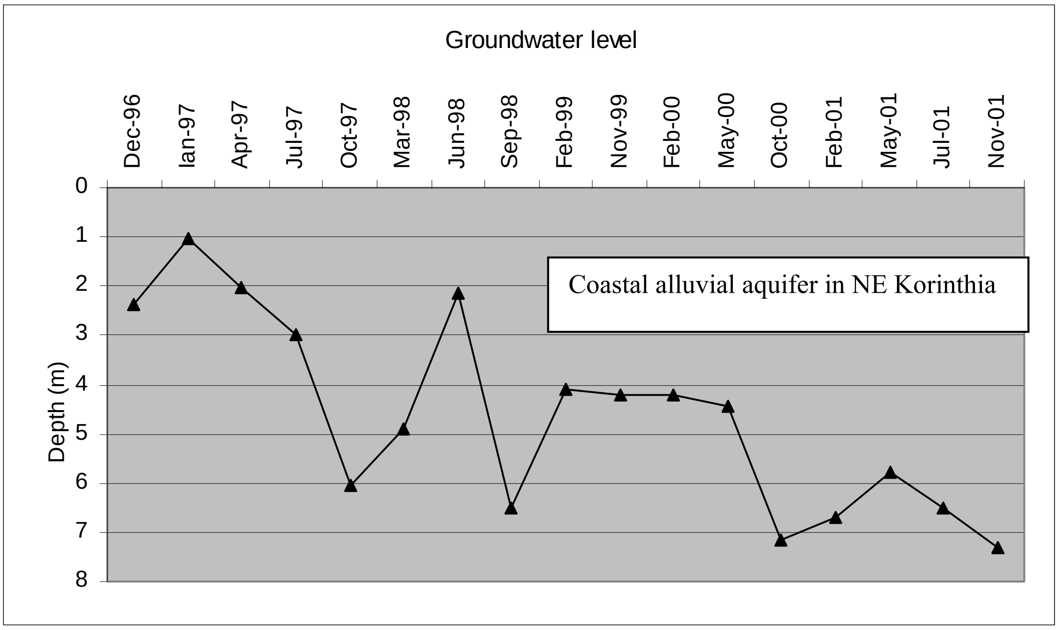

Figure 3. Hydrograph of groundwater table fluctuations (meters from the ground surface) in coastal aquifer system of Asopos basin

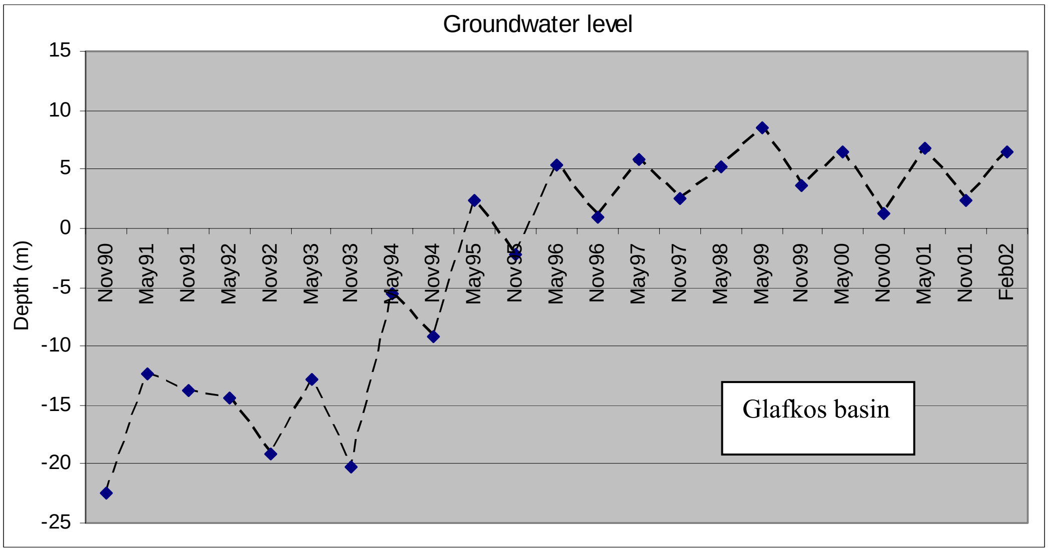

Figure 4. Hydrograph of groundwater table fluctuations (meters from the ground surface) in the coastal alluvial aquifer of Glafkos basin

Groundwater flow approximately follows the surface drainage pattern. Overexploitation has caused a decline of groundwater levels in aquifer systems and changes in the direction and velocity of groundwater flow. The average hydraulic conductivity is $k = 2x10^{-4}$ m s^{-1} as deduced from the conducted pumping test analyses (Voudouris, 1995, Koumantakis *et al*., 1999). The yield of boreholes ranges from 10-80 m^3 h^{-1}.

Groundwater recharge of the aquifer mainly takes place by seepage through the riverbed and direct infiltration during rainfall. Urbanization in the coastal part has resulted in the construction of buildings and an increase in paved areas causing a reduction in direct groundwater recharge and the generation of additional surface runoff.

2. Aquifers of Plio-Pleistocene deposits

These aquifers are hosted in the terrestrial facies of neogene deposits (conglomerates, sandstones), forming a multiple aquifer system, which is at least 200 m thick. For example, the aquifer of Patras industrial area is the main aquifer for its groundwater resources with annual abstraction about of $2x10^6$ m^3 (Voudouris *et al*., 2002c). The age of groundwater from aforementioned aquifer, based on tritium and radio carbon dating ranges from 40 to 600 years old. (Voudouris, 1995).

Transmissivity (T) and Storage coefficient (S) values vary between T = 55-110 m^2 d^{-1} and $S = 8x10^{-4}$-$2x10^{-3}$, respectively. The aquifer of Pleistocene deposits (Tyrrhenian) in the eastern part has a low potential, which is attributed to the heterogeneity of its clastic material, its limited thickness and its fragmentation as a result of tectonic faulting (Stamatis and Voudouris, 2003). Analysis of pumping test data from boreholes drilled in Upper Pliocene conglomerates showed double porosity features and Transmissivity values between 45-62 m^2 d^{-1}.

3. Karst aquifers

The karst aquifers are hosted in carbonate rocks which show a high water permeability due to its well developed wide jointing and its karstification. The yield of boreholes ranges from 30 to 250 m^3 h^{-1} and Transmissivity varies between 50 and 950 m^2 d^{-1} (Voudouris, 1995). Karst aquifer systems often discharge groundwater through large springs, e.g. Stimafalia, Mana, Agia Varvara, Chalandritsa, Skiadas, Kalousi, Chrisopigi etc (Skayias 1978). The location of springs are shown in Figure 1.

Seawater intrusion phenomena in karst aquifers have recorded in recent years, due to intensive exploitation (Kamari, Spathovouni). In the eastern part of the study area the karst aquifer is in direct hydraulic communication with the sea, contributing to seawater intrusion. A common feature in the karst system surrounding this area are solutions channels, which discharge water as submarine springs (Loutra Elenis, Almiros, Korfos).

4. GROUNDWATER QUALITY

Groundwaters typically have a large range in chemical composition attributing to differences in: interaction with lithosphere, atmosphere and biosphere, recharge rate, anthropogenic activities, temperature and pressure.

In order, to determine the groundwater quality, the chemical analyses results of 460 samples were used. The majority of the analyses were carried out in the laboratory of Hydrogeology of the Patras University. The water quality data from other investigations (Agriculture ministry, General Chemical laboratory of the state, Institute of Geology and Mineral Exploration) are used in the current study for comparative purposes (Daskalaki, 2002). The measured chemical parameters of 50 representative groundwater samples are presented in Table 5 and the sampling location in Fig. 6.

The pH values are greater than 7, indicating the slightly alkaline character of groundwater. Electrical conductivity is low in freshwater recharge area and progressively increases towards the coastline (Fig. 5). In recharge areas the prevailing ions are Ca^{2+} and HCO_3^-. Moving seawards Na^+, Cl^-, K^+ are the prevailing ions. The lowest concentration of sulfate (SO_4^{2-}<30 mg l^{-1}) occurs in groundwater from mountainous area.

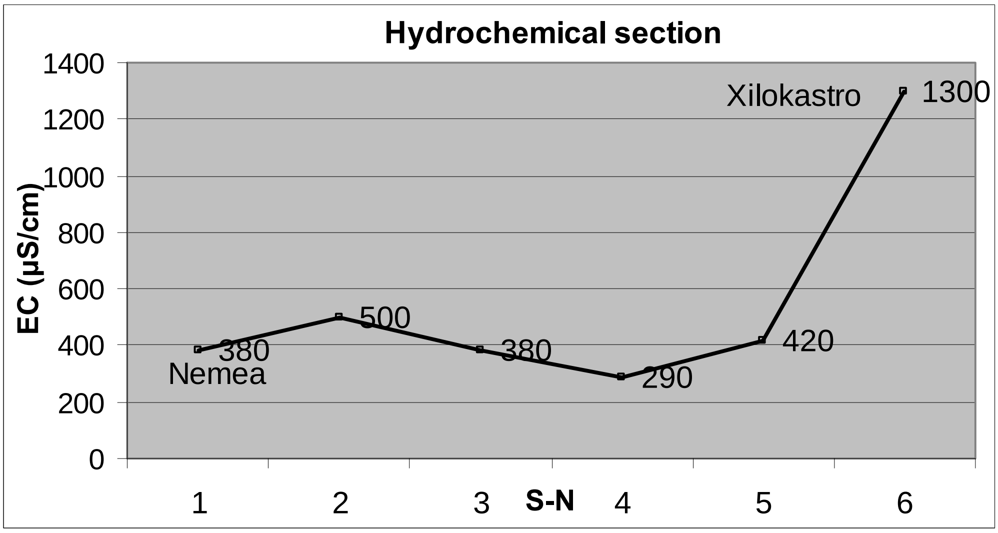

Figure 5. Hydrochemical section from south to north in Asopos basin

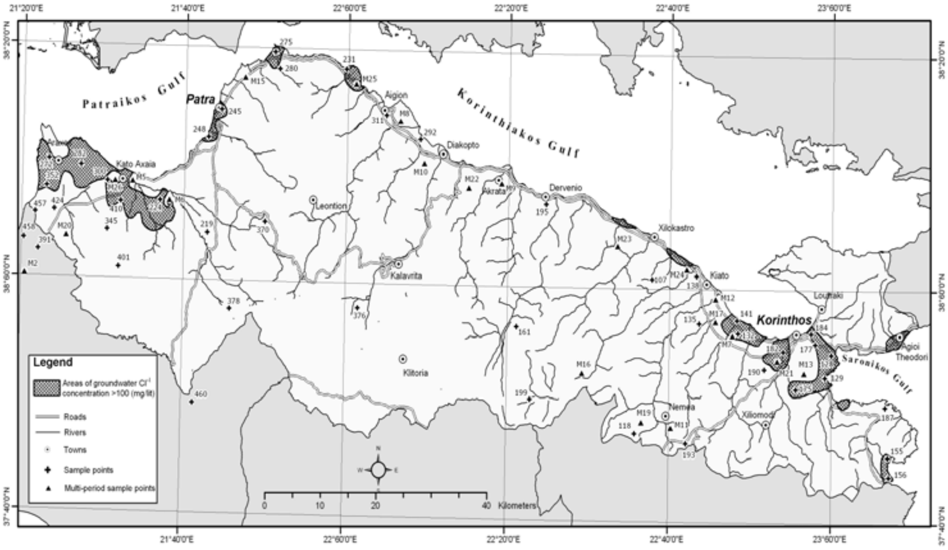

Figure 6. Areas affected by seawater intrusion (Cl$^-$ concentration >100 mg l^{-1})

The waters are of various hydrochemical types: Ca-HCO_3 (freshwater of recent infiltration from mountainous area suitable for drinking purpose), Na-HCO_3 (this type indicates ion-exchange phenomena and characterizes a transition zone) and Na-Cl (typical brackish water from coastal aquifers affected by seawater intrusion, in which the ions Na^+ and Cl^- predominate). The Mg-HCO_3 type of groundwater is recorder in Loutraki alluvial aquifer.

The shallow alluvial aquifers are under risk of anthropogenic pollution (nitrate pollution). Groundwater in urban areas has been contaminated to varying degrees. Central municipal sewage-treatment systems exist in the big cities (Patras, Aigio, Korinthos, Kiato, Xilokastro). In other places municipal waste water is generally collected into uncontrolled septic tanks, contributing to groundwater contamination. In mountainous area, the municipalities use the main fault zones and karstic features as sites for their solid waste and wastewater disposals. Surface water quality deterioration is also apparent and is mainly attributed to the uncontrollable discharge of untreated olive oil mill effluent.

4.1 Seawater intrusion

The saltwater intrusion is caused by over-pumping, water abstraction from great depths, and lack of reliable water resources management. The overexploitation of coastal aquifers always produces a lowering to the water table levels. When the extracted volumes are greater than the recharge, even on local base, a salinisation process begins in the aquifer as the seawater flows upon the land. The seawater intrusion has been favored by some preferential paths, depending upon the hydrogeological conditions of each area.

Based on chemical analyses, seawater intrusion takes place in areas (Fig. 6) near utilized groundwater sources (borehole fields). In the western part seawater intrusion phenomena are recorded between Metochi and Sagaiika, Lakopetra, Araxos and Glafkos basin (Voudouris *et al*., 2004a). Based on piezometric measurements, the seawater intrusion zone extend up to 1 km from the shore in the coastal alluvial aquifer of Glafkos basin (Mandilaras *et al*., 1999).

In the eastern part high chloride concentrations are depicted in the coastal region between Lecheo and Vraxati, Melisi and Kamari and Kexrees. According to Stamatis and Voudouris (2003), a comparison of Cl^- concentration distribution between 1968 and 1998 indicates that, seawater intrusion expanded in eastern Korinthos area, as a result of overexploitation of the aquifer. A gradual decline of chloride concentrations from coastline to recharge areas is observed (Panagopoulos *et al*., 2001).

4.2 Nitrate contamination

Nitrate is the most abundant nutrient in groundwater. As shown in Table 5, nitrate concentrations range between 0-186 mg l^{-1}; the mean nitrate value is 21.7 mg l^{-1} and the max admissible concentration of 50 mg l^{-1} set by EU (1998) for drinking water, is exceeded especially in the eastern part of study area (Voudouris *et al*., 2004b). Possible negative health effects of high nitrate concentrations are methemoglobulinemia, especially for infants. Nitrates are noticeable throughout the entire region rendering most of groundwater improper for human consumption.

From Fig. 7, it can be seen that sites with high concentration of nitrate (>50 mg l^{-1}) occur in: a zone extending near to Lapas, Kato Achaia (western part of the study area) and Zevgolatio, Examilia, Ancient Korinthos, Agios Basilios (eastern part of the study area).

The previous mentioned areas are characterized by intense agricultural activity and the high nitrate concentrations in groundwater are related to over-fertilization. Also, localized high phosphate concentrations (PO_4^{3-}>0.3 mg l^{-1}) can be attributed to the use of fertilizers.

Nitrate concentrations are higher in the dry season and progressively reduce in the wet season. Based on the average hydraulic parameters of the coastal alluvial aquifer systems of Korinthia prefecture, it is calculated that a period of 16 years is required to restore groundwater quality to a background level of 15 mg l^{-1}, provided that complete cessation of fertilization is enforced (Voudouris *et al*., 2004b).

High nitrite (NO_2^-) concentrations and NH_4^+ are recorded in urban areas and can be associated with the human activities.

4.3 The change of the groundwater quality through time

Table 6 presents the chloride and nitrate concentrations, based on chemical analyses results of 26 representative groundwater samples, during the years 1997 and 1999. Figure 8 shows the chloride concentration changes of selected groundwater samples in this period. As can be seen, Cl^- concentration increases in some coastal aquifers, during the period 1997-1999 (Daskalaki, 2002). The concentration of chloride in groundwater has increased to more than 6500 mg l^{-1} in some boreholes at the end of the prolonged drought periods (Fig. 9).

Figure 10 shows the nitrate variation of selected groundwater samples during the years 1997 and 1999. In 1999, the conditions remain the same in most sites. A comparison of nitrate concentration from phreatic aquifer in Korinthos area, between the periods 1968 and 1998 indicates that, the deterioration of groundwater quality is attributed to nitrate pollution, originating from the excessive use of fertilizers (Stamatis and Voudouris, 2003)

Table 5. Chemical composition of 50 representative groundwater samples; concentrations in mgl^{-1}, Electrical Conductivity in µS/cm (sampling location as seen in Fig. 6)

No	**pH**	**EC**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**Cl^{-}**	**NO$_3^-$**	**SO$_4^{2-}$**	**HCO$_3^-$**
107	7	1060	155	39	33	2	33	68	122	430
118	7	250	97	3	5.1	2.2	17.7	0	12	110
128	7	1050	59.8	55.9	9.2	1.2	134	25	88	325
129	7.6	850	333	423	3450	223	6384	3.7	901	560
132	7.1	780	40	68	30	2.8	113	30.5	156	450
135	7.05	1210	48	52	167	4.5	99	57	28	256
138	6.9	1385	198	69	78	4	92	89	212	498
141	7	1200	139.5	57.8	12.5	2.3	109.9	2	115	450
155	7.6	550	353	627	5336	313	9752	4.3	1385	306
156	7.4	510	361	856	6900	340	12695	4.3	1807	259
161	7.7	505	67	7	2	1	5	2.5	6	226
175	7.45	760	107	149	247	50	339	17.6	365	664
177	7.85	780	38	81	90	0.7	172	44	56	351
182	7.8	1950	125	105	173	9	295	126	185	730
184	7.38	840	174	521	474	62	2329	19.8	24	347
187	7.3	690	99.4	11.7	9.2	8.6	17.7	17.4	25.9	316
190	7.4	820	89.8	4.4	9.66	0.39	21.3	3.7	3.8	274.5
193	7	600	99.6	21.5	10	0.2	28.3	9	47	190
195	7	380	63.8	26.7	3	0.4	14	5	35	332
199	7	420	75.7	7	3	0.4	21.2	10	6	310
219	7.78	900	16	5.52	185.5	0.9	114	2.3	2	386.5
224	7.11	1350	193.6	16.8	82.4	3.8	131	1.7	190	450.2
231	7.16	325	95.2	4.6	7	1.1	9	2.6	34	261.1
245	7.38	1050	106.8	1.2	115.3	3.7	207	2.6	48	262.3
248	7.98	380	119.2	2.4	11	1.5	14	14.7	19	335.5
272	7.5	1330	174.3	34	59.8	31.3	106.3	0	408.3	158.6
275	7.6	815	104.2	21.9	34.5	6.2	95.7	0	9.61	341.7
280	7.4	1700	208.4	47.4	87.4	43.	393.5	186	105.7	292.9
282	7.3	1650	350	51.1	68.9	43.2	233.9	31	240	286.8
292	7.8	400	40.1	24.3	2.76	3.1	3.5	11	4.8	244.0
300	7.6	1950	160.3	25.5	133.3	82.4	386.4	4.5	120.1	2806.6
311	7.4	440	80.2	3.6	4.6	3.9	7.1	16	19.2	244.1
345	7.4	1160	120.2	38.9	45.9	19.5	141.8	30	134.5	299
352	7.5	1820	60.1	48.6	147.1	156.4	283.6	22	19.2	549.1
370	7.87	340	85.8	1.2	6.8	0.7	3.9	1.55	0.05	251.6
376	7.85	239	65.93	3.0	2.3	0.9	8.8	1.3	9.6	215.4
378	8.04	274	70.1	2.4	6	0.4	12	1.3	2.0	217.2
383	7.27	940	136.3	17.0	46	19.5	60.3	5	91.3	402.7
385	7.75	680	120.2	4.9	29.9	27.4	39	25	57.6	329.5
388	7.37	550	92.2	4.8	6.9	35.2	7.1	3.3	43.2	256.2
389	7	1090	240	19.5	28.9	27.3	38	25.1	160	317.3
390	7.3	1400	304	68.3	36.8	23.5	69	31.2	305	329.5
391	7.4	700	172	7.3	23.6	3.3	31	3.96	105	345
392	7.3	800	204	2.4	25.3	5.5	38	4.4	110	396.6
401	7.24	689	108.5	15.8	15.6	1.1	8	3.6	18.5	373
410	7.12	1120	147	23.5	38.4	4.7	105	13.7	31.2	364
424	7.58	865	19.6	96.6	44.5	3.4	83	33.2	13.7	378
457	7.29	1080	101	29.2	83.8	3.6	98	34.6	33.8	378
458	7.13	1138	76.8	26.2	144	6.8	120	36.1	83.5	345
460	7.4	410	74.1	3.65	6.9	0.8	17.7	0.1	4.8	225.7

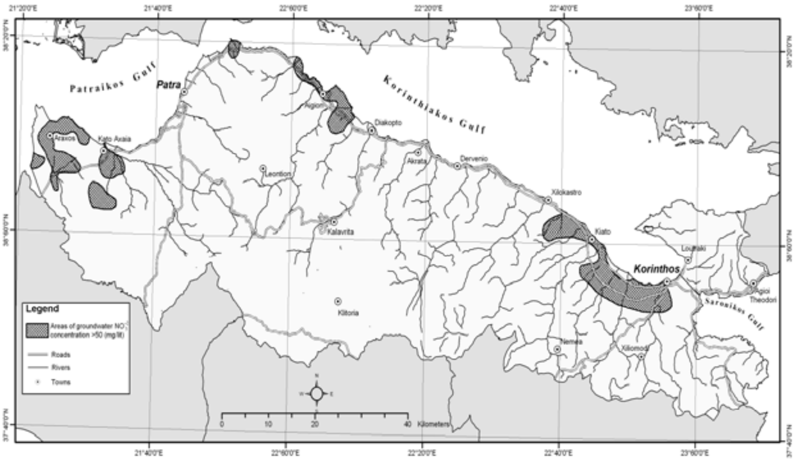

Figure 7. Areas affected by nitrate pollution (${NO_3}^-$ concentration >50 mg l^{-1})

Table 6. ${NO_3}^-$ and Cl^- concentrations (mg l^{-1}) of 26 selected groundwater samples in the years 1997 and 1999 (sampling location as seen in Fig. 6)

No	YEAR	NO_3	Cl	No	YEAR	NO_3	Cl	No	YEAR	NO_3	Cl
M1	1997	25.9	76	M10	1997	7.48	11	M19	1997	57.6	5
M1	1999	28	31	M10	1999	7.7	11	M19	1999	62	7
M2	1997	6.2	44	M11	1997	19.8	17	M20	1997	18.5	43
M2	1999	5.3	44	M11	1999	27.2	25	M20	1999	22	46
M3	1997	26.4	51	M12	1997	35.2	81	M21	1997	64.7	88
M3	1999	33	62	M12	1999	84.5	91	M21	1999	52.8	120
M4	1997	4.4	28	M13	1997	27.9	30	M22	1997	26.8	
M4	1999	2.2	35	M13	1999	29	55	M22	1999	33.2	
M5	1997	6.6	26	M14	1997	14.5	32	M23	1997	33	
M5	1999	7.1	23	M14	1999	20.2	42	M23	1999	41	
M6	1997	21.6	26	M15	1997	35.2	29	M24	1997	37.8	
M6	1999	11.4	41	M15	1999	32.1	17	M24	1999	45	
M7	1997	34.7	41	M16	1997	6.6	20	M25	1997	56.7	86
M7	1999	62.2	51	M16	1999	4.4	15	M25	1999	62	109
M8	1997	15.9	44	M17	1997		55	M26	1997	58.5	30
M8	1999	35.6	22	M17	1999		320	M26	1999	66	32
M9	1997	6.2	14	M18	1997	104.2	35				
M9	1999	7.5	65	M18	1999	110	36				

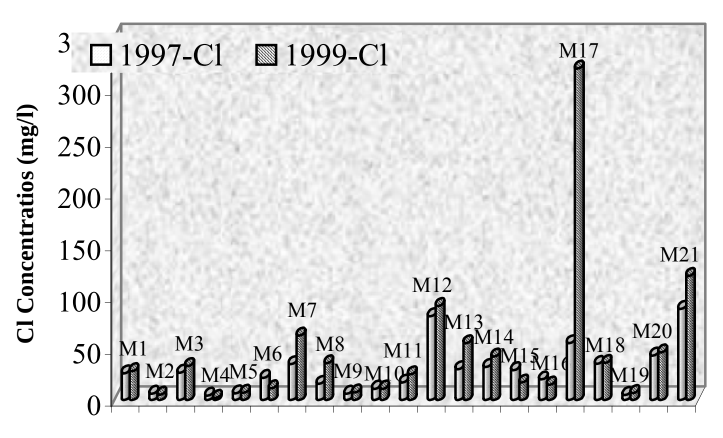

Figure 8. Chloride variation of representative samples during the years 1997 and 1999

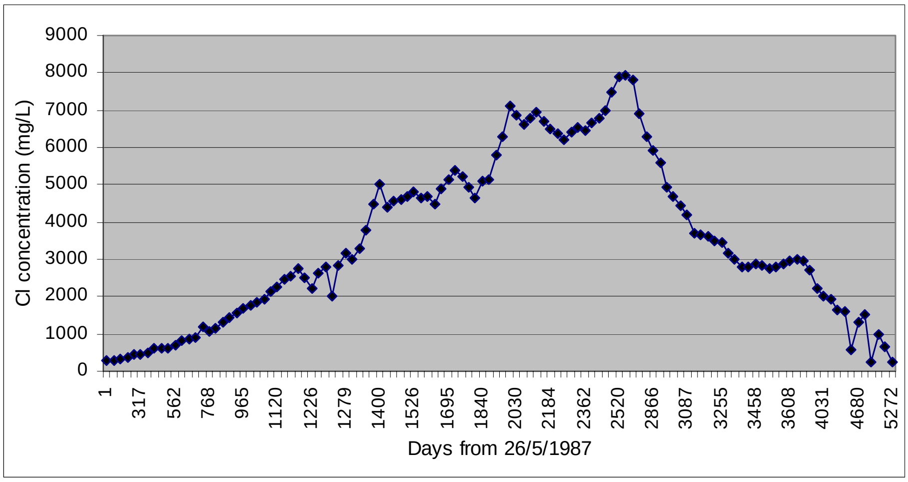

Figure 9. Chloride concentration (mgl^{-1}) fluctuations in groundwater from the coastal alluvial aquifer of Glafkos basin, 1987-2001

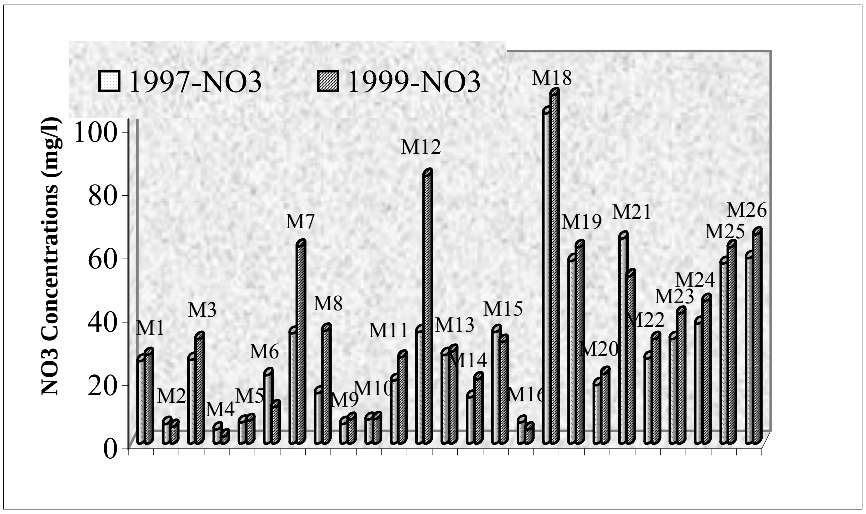

Figure 10. Nitrate variation of representative samples during the years 1997 and 1999

5. CONCLUSIONS-PROPOSAL SOLUTIONS

Groundwater is an important source of the water for domestic and irrigation use and it supplies at least 80% of all the needs of North Peloponnesus. The main aquifers are the alluvial, the aquifers of coarse grained Plio-Pleistocene deposits and the karst aquifers. Karst aquifer systems discharge groundwater through springs; coastal brackish water springs and inland freshwater springs.

Degradation of groundwater quality is mainly caused by: seawater intrusion and nitrate pollution. The coastal part of this area is characterized by ongoing urbanization, tourism development and intensive agriculture. As a result, in some coastal aquifer systems of the study area a negative water balance is established, triggering seawater intrusion.

Intensified fertilization has led to considerable groundwater quality deterioration, as evidenced by the increased nitrates concentration. Other sources of groundwater pollution are leaking septic tanks in urban areas. Groundwater alone cannot meet the water supply requirements in the study area and thus a need exists to supplement with surface water. The total annual surface runoff of the study area is estimated to be 0.9-1.2x10^9 m^3.

An integrated management strategy should apply to develop new ways of providing an adequate water source in coastal areas. This strategy could be based on the conjunct use of (a) groundwater, (b) the abundant discharge of river/torrents (Piros, Sithas, Asopos), (c) the discharge of freshwater springs, and (d) the rich and high quality groundwater reserves of the mountainous region (Killini, Feneos), which are practically not exploited.

The following recommendations are proposed in order to restore the negative water balance, to provide adequate water and to improve the water quality in coastal areas of North Peloponnesus:

1. Exploitation of surface water and groundwater simultaneously. This scheme allows a maximization of water use efficiency. Construction of Asopos dam in eastern part and Parapiros dam in western part for the twin purposes of providing drinking and irrigation water. In addition, the potential hydro-energy can be developed. Construction of small interception dams in the main streams of the hilly region, aiming at retardation of wintertime torrential flows and increasing groundwater recharge from streambed infiltration. In addition, these dams improve water supplies for agriculture requirements.
2. Reduction of groundwater abstraction should be applied in coastal areas, that have affected by seawater intrusion. Utilization of the treated wastewater from plants for irrigation purposes and artificial recharge. Under this strategy groundwater abstractions for irrigation would reduce significantly.
3. The distribution systems for drinking and irrigation purposes, from which approximately 20-30% of the water is lost, should be repaired. Water-saving techniques such as spray irrigation, drip irrigation should be applied in order to decrease the groundwater quantities for agriculture.
4. The aquifer recharge application from the rivers wintertime discharge through deep boreholes or infiltration ponds could improve the groundwater regime in some aquifers. According to the results from an artificial recharge program (Koumantakis *et al*., 1999) in the coastal aquifer system of Korinthia it is concluded that an annual volume of $3.5x10^6$ m^3 originating from Asopos river could augment groundwater budget and improve the groundwater quality. Another artificial recharge test has been constructed in Patras industrial aquifer. The simulated results indicate that, aquifer recharge with 800,000 m^3 water in wet period December-March via 10 deep boreholes limits the drawdown at the end of dry period, including the irrigation period when the pumping has been increased (Voudouris *et al*., 2002c).
5. Planning of surface water protection measures such as banning of olive oil mill and domestic effluent disposal in rivers and streams, as well as construction of proper environmentally compatible landfills.
6. For solving the problem of water shortages in coastal areas, long-distance water allocation and transfer schemes should be built from mountainous areas.
7. Protection zones should be establish for both surface and groundwater resources in important water supply regions.

Finally, future investigations of the sustainable management of water resources in the North Peloponnesus would benefit by hydrological data monitoring, isotopic analysis, water quality monitoring, land use monitoring and computer modelling to simulate the water cycle.

REFERENCES

Daskalaki, P., (2002), Contribution to chemistry and quality of groundwaters in Greece, Ph.D. Thesis. Dep. of Geology, University of Patras.

Daskalaki, P., Voudouris, K., Diamantopoulou, P., (1998), Hydrochemical study of North Peloponnesus quaternary and plio-pleistocene aquifers, Proc. Int. Con. Protection and restoration of the environment IV, Sani, Greece, Vol. I, 108-116.

E.U. Council (1998), Council directive 98/83 about water quality intended for human consumption, Official paper of the European Communities, V. L330, 32-54.

Freeze, A. and Cherry, JA. (1979), Groundwater. Pentice Hall, Englewood cliffs.

Kasimis X., Papadopoulos A, Sousounis G and Stravopodis S. (1998), Contribution to the colloquy on the development of the Prefecture of Corinth, Unpublished report (in Greek).

Koukis, G., Nikolaou, N., Pirgiotis, L. (1996), Runoff and proposed storage works in the county of Korinthos. Proc. 2th Panellenic Conference, Geotechnical chamber of Grecce, Larisa, Vol. II, 910-924.

Koumantakis, J., Panagopoulos, A., Stavropoulos, X., and Voudouris, K. (1999), Application of aquifer artificial recharge in the coastal alluvial basin of the northern part of Korinthos Prefecture, Proc. 5th Conf. on Hydrogeology, Nicosia, Cyprus, 65-80, (in Greek).

Lambrakis, N., Voudouris, K., Tiniakos, L., Kalergis, G. (1997), Impacts of drought and overpumping on the Quaternary aquifers of the Glafkos basin (Patras region, W. Greece). Environmental Geology, 29 (3/4) February 1977, 209-216.

Mandilaras, D., Voudouris, K., Lambrakis, N. 1999. Fluctuation in the groundwater quality of the alluvial aquifer of Glafkos basin (Achaia, Greece). Proc. 5th Hydrogeological conference, Nicosia, Cyprus, 407-422.

Nikolaou, N., Koukis, G., Lambrakis, N. (1997), Rainfall and landslide manifestation correlation in Korinthos, Greece. Proc. Engineering Geology and Environment. Vol. 1, 919-924. Balkema.

Panagopoulos A., Voudouris, K., Koumantakis, J., and Hionidi, M. (2001), Groundwater evolution of the northern Corinthian region coastal aquifer system, as indicated by Hydrochemistry, Proc. 9th Int. Conf. of the Geological Society of Greece, Athens, Greece, 2001.

Panagopoulos, A., Voudouris, K, Hionidi, M., Koumantakis, J. (2002), Irrational water resources management impacts on the coastal aquifer system of Korinthia. Proc. International Conference «Restoration and Protection of the Environment V», July 2002, Skiathos. Volume I, 419-426.

Skayias, St. (1978), Inventory of karstic springs of Greece. Vol. 1, Hydrological and Hydrogeol. Investigations, No 28. Institute of Geological and Mining Research.

Stamatis, G., Voudouris, K. 2003. Marine and human activity influences on the groundwater quality of southern Korinthos area (Greece). Hydrological processes, 17, 2327-2345 (2003).

Voudouris, K. (1995), Hydrogeological conditions in NW Achaia. Ph.D. Thesis. Dep. of Geology, University of Patras.

Voudouris, K, Lambrakis, N., Tiniakos, L., Kallergis, G. (1997), Contribution to the study of the water balance in the Patras area. Proc. 7th Conference of the Hellenic Hydrotechnical Assosiation, Patras, 50-58 (in Greek).

Voudouris, K. (1999), Spatial distribution of rainfall in North Peloponnesus. Proc. 5th Conference on Hydrology, Nicosia, Cyprus, 245-254 (in Greek).

Voudouris K., Panagopoulos, A. and Daniil, D. (2000), Implications to surface water quality of Korinthos Prefecture from anthropogenic activities, Proc. Int. Conf. Protection and Restoration of the Environment V, Thassos, Greece, 2000.

Voudouris, K, Hionidi, M., Panagopoulos, A., Koumantakis, J. (2002a), Extreme climatic events in the Prefecture of Korinthos (Greece) and their impact on groundwater resources. Proc. 5th International Conference “Water resources management in the era of transition”. European Water Resources Association. Athens, 107-114.

Voudouris, K., Panagopoulos, A., Markadonis, K. (2002b), Hydrological balance and possibilities of sustainable water resources management in Stimfalia basin (prefecture of Korinthos). Proc. 6th Pan-Hellenic Geographical Conference. Vol. II, 327-334 (in Greek).

Voudouris, K., Diamantopoulou, P., Giannatos, G., Zannis, P. (2002c), Results of groundwater recharge on the confined aquifer in Patras industrial area. Proc. 6th Conf. on Hydrogeology, Xanthi, 47-58, (in Greek).

Voudouris, K., Nikas, K., Antonakos, A. (2004a), Study of evolution of the seawater intrusion zone in coastal aquifers. Proc. 10th Int. Conf. of the Geological Society of Greece (in press).

Voudouris K., Panagopoulos, A., Koumantakis, J. (2004b), Nitrate pollution in the coastal aquifer system of the Korinthos Prefecture (Greece). Global Nest: The International Journal, **6**(1), 31-38, 2004.