A QUALITATIVE-QUANTITATIVE STUDY OF WATER AND ENVIRONMENTAL POLLUTION AT THE BROADER AREA OF THE MYGDONIA BASIN, THESSALONIKI, N. GREECE

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ABSTRACT

The Mygdonia drainage basin, located about 10 km NE of Thessaloniki town, encloses the Lakes Koronia, Volvi and Vromolimnes, and contains Pleistocene and Holocene loose sediments formed on an active tectonic depression. A shallow phreatic aquifer (d<50 m) and a deep one (d=80-500 m) are recognized in the basin, while at depths of 50-80 m impermeable clayey layers of unilateral to lensoid formation predominate. During the period 1996-2000, the drop in the water table of the phreatic aquifer in the area of Lake Volvi was constant (0 to 1.2 m), while in Lake Koronia this was 0.11 to 7.59 m. The decreasing annual natural water flows, combined with the urban and industrial impact, lead to water pollution (high pH, E.C., Na, K, Cl, F and SO_4) and ecological death.

KEYWORDS: Mygdonia, Koronia, Volvi, aquifer, water, quality, pollution

I. INTRODUCTION AND GEOLOGICAL SETTING

The Mygdonia drainage basin is located approximately 10 km NE of Thessaloniki town (latitude 40°40', longitude 23°15'), and encloses the Koronia and Volvi Lakes, the town of Langadas and the villages of Scholari, Rendina and Nea Apollonia (Fig. 1).

The basin is Neogene to Quaternary, has an E-W orientation, formed as a graben with an E-W alignment and overlies (from E to W) the metamorphic basement with rocks, such as gneisses, schists, marbles and granitic intrusions of the Serbomacedonian massif and schists, quartzites, limestones and mafic rocks of the Circum Rhodope belt (IGME, 1978).

The lowland area of the Mygdonia basin is dominated by a Pleistocene loose terrace system (gravel, sand, sandy clays etc.) outcropping at the graben margins and Holocene alluvial deposits, lacustrine sediments, deposits in river and torrent beds and valley deposits which are now found in the middle of the graben (IGME, 1978). These formations comprise the Mygdonian system according to Psilovikos (1977). This graben has been activated since the early Quaternary and continues today by widening a few cm per year according to Psilovikos and Sotiriadis (1983), Papazachos (pers. comm.) and Chatzipetros and Pavlidis (1998). The total thickness of the Pleistocene-Holocene sediments approaches 500 m (west of Koronia Lake, boreholes, geophysics, study of BRGM). In the south margin of the graben, in contact with the graben, a Pro-Mygdonian formation of relatively impermeable semi-loose late Miocene-early Pliocene sediments is of a lesser importance.

The aim of this study is to reveal the way of water pollution in the Mygdonia drainage basin and to evaluate the contribution of water shortage to worsening the environmental impact from the above problem.

II. HYDROGEOLOGICAL DATA

The Mygdonia drainage basin (Fig. 2) covers an area of 2026 km^2, 656 of which belong to the planal (lowland) part. The two Lakes Koronia and Volvi occupy an area of more than 100 km^2. There used to be another two lakes to the North of the Lake Volvi, in the Vromolimnes graben (Psilovikos et al., 1977), the drained Lakes Mavrouda and Lantza. The maximum altitude (1201 m above the sea level) of the Mygdonia basin is found in its SE part (the Chortiatis mountain) and the average altitude is 338 m above the sea level.

The metamorphic rocks were brecciated. Their infiltration coefficient of the precipitation, depending on the brecciation degree, slope of morphology etc., can be estimated as 3 to 10% (IGME, unpublished reports). The total permeability

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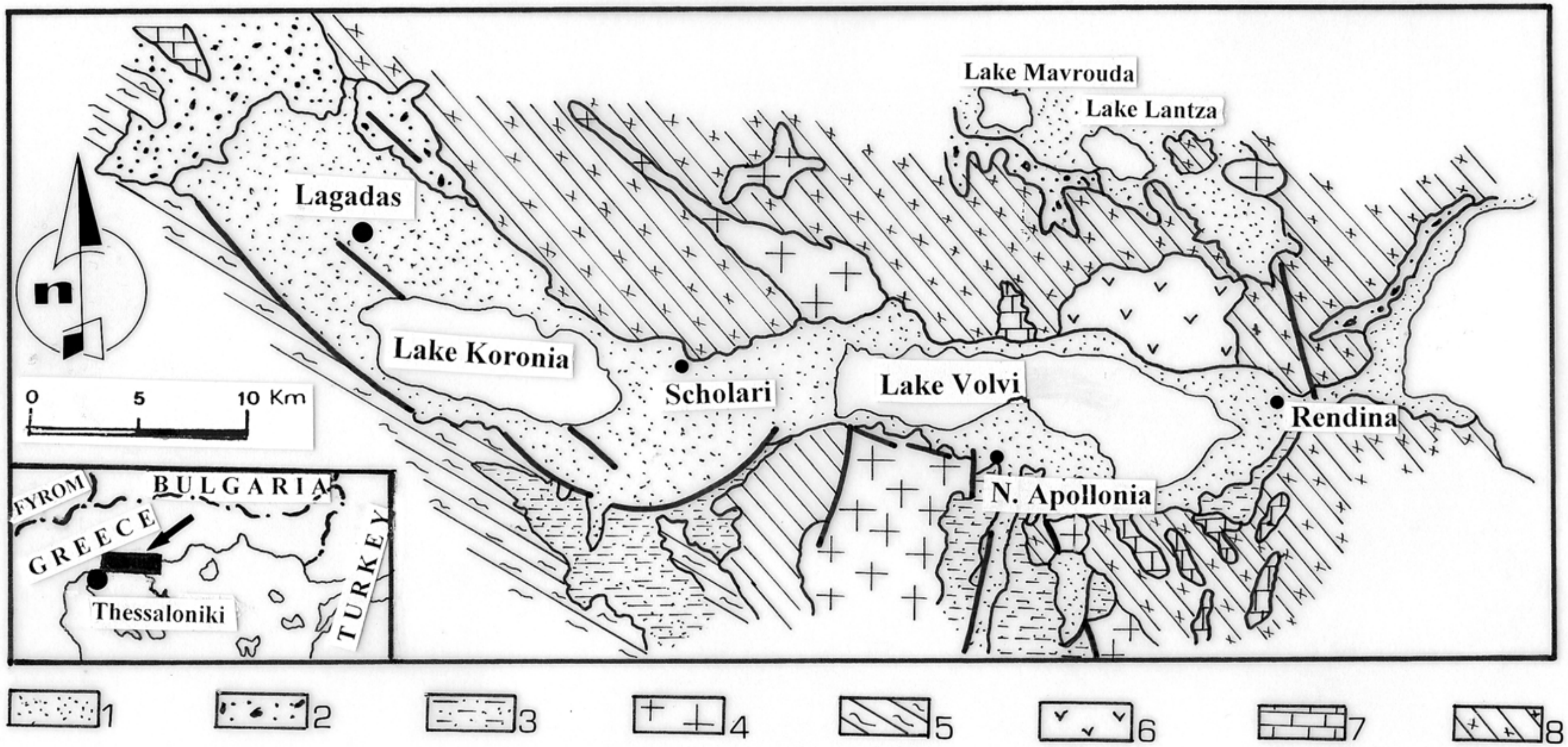

Fig. 1. Geological map of the Mygdonia basin.

1. Alluvial deposits, lacustrine sediments, deposits in river and torrent beds, valley deposits and a loose terrace system.
2. Clays, sands and terrestrial phase conglomerates.
3. Marls, red clays and sands of lacustrine and terrestrial origin.
4. Acid to intermediate intrusive rocks.
5. Schists, quartzites, limestones and mafic rocks.
6. Amphibolites.
7. Limestones and marbles.
8. Gneisses and schists.

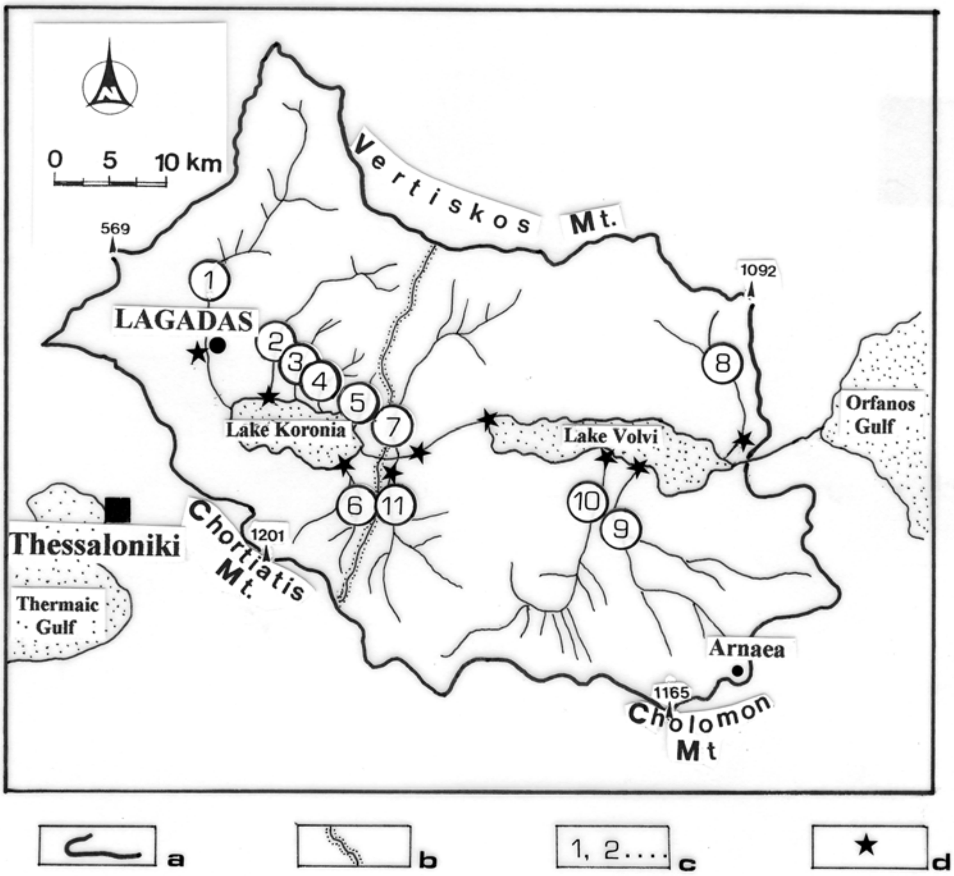

Fig. 2. The Mygdonia hydrological basin.

a. Watershed of the Mygdonia basin.

b. Watershed that divides the Mygdonia basin into the sub-basins of Koronia and Volvi.

c. Point of infiltration measurement for the particular water stream in the contact of loose formations with the metamorphic rocks. The numbers correspond to the water stream numbers of Table 1.

d. Point of infiltration measurement for the particular water stream into the loose formations.

in the brecciated gneisses along faults can be estimated by microtectonic observations (Kilary method) to be $K=2.3*10^{-6}$ to $7.1*10^{-7}$ m/sec (Demiris, unpublished).

In the metamorphic rocks of the basin, as it is found from groundwater supply boreholes, the groundwater circulates in faults and fractures in depths greater than 30 m with $Q=10-25$ m^3/h. The groundwater, which circulates in the metamorphic rocks is discharged in the loose formations of the basin.

The voluminous loose deposits are found in the W part of the Mygdonia basin (Lake Koronia) while the opposite exists in the middle to E part of the basin. From the present surface to the depth of ~50 m, a shallow phreatic aquifer is found, characterized by a fast hydraulic loading and unloading. The depth of 50 to 80 m is predominated by clayey layers of unilateral to lensoid formation, while sands and gravels become less abundant. In the depth of 80 to 500 m (in the middle of the basin), the groundwater is under pressure and the host Quaternary formation is characterized as a deep aquifer. According to Vatseris (1992), in the W part of the basin (Koronia area) there is no groundwater circulation between the shallow and the deep aquifer. On the contrary, recent data accomplished by IGME (unpublished) reveal the slow intercommunication of the groundwater between the phreatic and the deep aquifer.

The total drop in water table of the phreatic aquifer in the area of the Lake Volvi was constant (0 to 1.20 m) during the period of 1996-2000. For the same period, the total drop in water table for the area west of the Lake Koronia, where more than 5000 water supply boreholes operate, was 0.11 to 7.59 m.

III. HYDROLOGICAL DATA

The annual precipitation in the basin varies from 283 to 721 mm in the last 30 years (Langadas station, altitude 110 m). The climate type varies between mediterranean and continental. For the whole basin, Vatseris (1992) gives average annual temperature 13.55°C and average annual precipitation 584.9 mm.

The main form of surface drainage in the Mygdonia basin is the torrential flow which drains the mountainous part by feeding the low land of the Koronia and Volvi Lakes. Before 1985, a part of the torrential and river water used to infiltrate down to the loose formations of the phreatic aquifer and the rest by natural flow used to feed the lakes during the wet period. At present, this can only be observed in the area of the Volvi Lake, while in the area of Koronia Lake, the surface water is insufficient even for the feeding of the phreatic aquifer. Table 1, shows the mean (of 48 measurements/year for each water stream)

Table 1. Mean annual discharge of main water streams in the Mygdonia basin (in millions m^3)

No	WATER STREAM	Basin area (km^2)	1996	1997	1998	1999	2000
1.	RIVER BOGDANAS*	219	14.44	8.66	7.14	20.40	10.35
2.	TORRENT KOLCHIKOU*	76	2.20	1.59	1.42	4.00	2.96
3.	〃 DRAKONTIO*	<70	0.25	0.12	0.10	0.82	0.14
4.	〃 ANALIPSI*	<70	0.19	0.00	0.14	1.00	0.04
5.	〃 EVAGELISMOU*	<70	0.29	0.05	0.11	0.21	0.12
6.	〃 GERAKAROU*#	<70	2.74	1.44	1.02	2.99	1.43
7.	〃 SCHOLARIOU**	137	5.43	1.44	2.17	4.35	2.51
8.	〃 ARETHOUSA**	215	3.06	2.68	7.26	5.66	1.95
9.	〃 HOLOMONTA**	194	15.36	18.47	14.64	27.13	23.22
10.	〃 NEA APOLLONIA**	230	22.75	5.23	7.26	8.98	9.05
11.	〃 LANGADIKION**	140	5.95	4.38	4.26	12.51	4.57
TOTAL			**72.66**	**44.06**	**45.52**	**88.05**	**56.34**
Loose formations of Koronia sub-basin			20.11	11.86	9.93	29.42	15.04
Discharges on the Lake Koronia☼			**4.0**	**3.0**	**2.5**	**8.0**	**1.0**
Loose formations of Volvi sub-basin			52.55	32.20	35.59	58.63	41.30
Discharges on the Lake Volvi☼			**42.6**	**18.2**	**25.3**	**36.0**	**19.3**

*: Water streams discharged in the Lake Koronia. **:Torrents discharged in the Lake Volvi.

☼: Mean annual total surface discharge of water streams and torrents measured at the discharge point on the lakes.

#: The flow value of this torrent includes also the flow of the Vasiloudio torrent.

annual discharge of the main water streams (11 rivers and torrents) into the loose formations of the Mygdonia basin in the period of 1996-2000. In addition, the mean annual total surface discharges at the discharge point on the Lakes are also given for comparison. In the rest of water streams no surface flow could be observed. The flow measurements in the above 11 water streams have been made at their discharge location from the mountainous to the low land area. For some water streams, two flow measurements have been made in order to estimate the infiltration to the phreatic aquifer and the quantity of water that feeds the two lakes.

A large part of these flows, before reaching the lakes, is infiltrated down to the loose geological formations (from 12.6 to 100%). From these measurements of flow and infiltration, it is estimated that from 1996 to 2000 the Lake Koronia was fed with an annual average of 4 million m^3 of surface water, whereas, this figure for Lake Volvi is 28 million m^3 (Table 1). The surface of Lake Koronia in the 60s covered an area of 47.9 km^2, in the 80s around 42 km^2 (Zarkanellas, 1989) and now is around 25 km^2 with an average depth of 0.5 m. Similarly, the surface of Lake Volvi covers an area of around 75 km^2 and has had a 2.5 m drop in its water level from 1987 to 1997, which is a disturbing indication for its future.

The above data and hydrological balance studies of Lake Koronia from IGME (unpublished) for the period 1990-2000, point out to an annual water deficit of $15*10^6$ m^3. These data are conformable with balance estimations, based on the annual drop of groundwater table and are considered to represent the conditions in the Koronia sub-basin. From these data it is apparent that there is an urgent demand for water supply to Lake Koronia, which is vital for its existence and its ecosystem (Papakonstantinou et al., 1995). This, must be combined with a most suitable rational management of surface and groundwater, taking into account the local environmental, economic and social parameters. This is the only way to avoid the ecological death of the ecosystem in the Lake Koronia.

IV. BASINAL WATER QUALITY

IV.A. SURFACE WATER

The data from the analyses of surface stream water indicate their good quality, when no urban or industrial sewage water is discharged into them (Table 2, analysis 1: Bogdanas river, Fig. 2). When there is anthropogenic-industrial pollution a remarkable change in the geochemical parameters can be seen (Table 2, analyses 2 and 3). By comparing analyses 1 (clean) and 2 (polluted) from different measuring sites of the Bogdanas river, a significant increase in pH, conductivity, Na, K, Cl, SO_4, NO_3 and HCO_3 can be observed. Sample 3 concerns industrially polluted water from a canal leading to the Lake Volvi.

Table 2. Anthropogenic influence on the surface stream water.

Sample No		1	2	3
pH		7.75	**10.20**	7.85
E.C. (Ms/cm)		315	**5880**	**4630**
Total Hardness (°F)		17.9	-	-
Na^+	mg/l	7.6	**889.2**	**1235.0**
K^+	mg/l	1.7	**28.0**	**64.0**
Ca^{++}	mg/l	49.8	23.1	6.8
Mg^{++}	mg/l	11.2	9.2	31.4
NH_4^+	mg/l	0.0	-	**2.3**
Cl^-	mg/l	19.8	**998.0**	**1398.4**
SO_4^{--}	mg/l	18.2	29.8	29.9
NO_3^-	mg/l	2.2	10.1	11.4
NO_2^-	mg/l	0.0	0.0	0.0
HCO_3^-	mg/l	188.3	600.0	211.5
PO_4^{---}	mg/l	0.1	-	-
F^-	µg/l	220	-	-

- : not analysed.

Shading indicates the concentrations which are higher than the maximum permitted levels by Hellenic Legislation for potable water (HGN, 2001).

Lake Koronia follows a course of intense environmental degradation for the last fifteen years, although protected by the Ramsar Treaty. If this situation continues for the foreseeable future, it will end as a saline dead bog.

The chemical composition of the Koronia Lake water (Table 3) reveals unusually high pH and conductivity values, K, Na, Cl, NH_4 and F. This is because the discharges of urban and industrial sewage waters into the lake are much higher in volume than the natural surface water flows in the lake. This, combined with the intense evaporation, which further reduces the amounts of water in the lake, is catastrophic for the future of lake (Katsiris et al., 1999; Antonopoulos and Gianniou, 1999).

Table. 3. Water quality of Lake Koronia in the period of 1981 to 1998.

Year		1981*	1990*	1992*	1995*	1996	1997	1998
pH		8.50	**9.39**	**8.90**	**10.21**	**9.29**	**10.12**	**9.54**
E.C. (μS/cm)		1360	1869	**2600**	**6100**	**3400**	**3650**	**7490**
Na^{+}	mg/l	**229.0**	**376.0**	**497.7**	**1140.0**	**680.0**	**951.5**	**1303.0**
K^{+}	mg/l	9.0	11.2	11.0	**20.3**	**13.0**	**21.5**	**28.2**
Ca^{++}	mg/l	4.6	10.1	17.6	8.0	13.6	11.2	94.6
Mg^{++}	mg/l	33.5	31.0	33.0	38.9	**58.8**	36.45	**100.2**
NH_4^{+}	mg/l	0.2	-	0.0	-	**1.7**	0.2	**6.2**
Cl^{-}	mg/l	177.0	**287.0**	**425.0**	**1347.0**	**514.0**	**992.6**	**1949.6**
SO_4^{--}	mg/l	60.0	78.0	64.0	-	185.0	175.8	218.1
NO_3^{-}	mg/l	0.0	0.50	3.70	-	10.6	9.3	12.4
NO_2^{-}	mg/l	-	-	0.0	-	0.0	0.0	0.0
HCO_3^{-}	mg/l	409.0	609.0	642.0	344.0	519.0	953.0	1830.0
F^{-}	μg/l	**2500**	**3000**	-	-	930	**2070**	**3170**

- : not measured.
Shading indicates the concentrations, which are higher than the maximum permitted levels by Hellenic Legislation for potable water (HGN, 2001).
*: IGME, unpublished data.

The hydrochemical conditions of Lake Volvi are shown in Table 4. The analyses show elevated values for the pH, electric conductivity, Na and Cl contents, which indicate that the course of the lake could be similar to that of

Table 4. Water quality of Lake Volvi.

Year		1995	1996	1997	1998
pH		**9.09**	**8.73**	**8.55**	8.34
E.C. (μS/cm)		970	943	1087	1102
Total Hardness (°F)		19.6	19.4	19.8	20.4
Na^{+}	mg/l	**178.2**	169.0	155.9	152.0
K^{+}	mg/l	6.7	9.4	7.8	5.9
Ca^{++}	mg/l	18.4	19.2	20.8	28.1
Mg^{++}	mg/l	36.5	35.5	35.5	32.6
NH_4^{+}	mg/l	0.1	0.0	0.1	0.0
Cl^{-}	mg/l	134.7	141.8	141.8	138.2
SO_4^{--}	mg/l	60.0	128.2	55.2	78.8
NO_3^{-}	mg/l	1.9	3.7	3.7	3.8
NO_2^{-}	mg/l	0.0	0.0	0.0	0.0
HCO_3^{-}	mg/l	360.0	359.9	-	356.3
PO_4^{---}	mg/l	0.6	0.3	-	-
F^{-}	μg/l	1760	1710	-	-

- : not measured.
Shading indicates the concentrations which are higher than the maximum permitted levels by Hellenic Legislation for potable water (HGN, 2001).

the Koronia Lake if this situation continues in the future. However, this will take longer to happen because the lake is much deeper than that of Koronia, there are fewer inhabitants around the lake and virtually no industries or significant agricultural land due to its smaller lowland area.

The chemical composition of the water in canals of the Mavrouda drained lake area (Table 5) is shown to be similar to that of the Koronia Lake. The elevated values of electric conductivity and the increased concentrations of Na, K, Mg, Cl, SO_4 and PO_4 characterize the water as brackish and unsuitable for use. Before drainage, the Vromolimnes use to have a high salt content, which used to be exploited in summer months (Psilovikos et al., 1977). Perhaps, the discharge (artificial) of Vamvakia river (from the Lake Lantza) to the Lake Volvi may also influence the water quality of the Lake Volvi (Psilovikos et al., 1977).

Table 5. Hydrogeochemical conditions of Mavrouda canal.

Year		1995			1996		
Sample No		1	2	3	1	2	3
pH		8.01	8.69	8.80	9.01	9.02	9.05
E.C. (μS/cm)		3980	8370	6340	6620	6230	4130
Total Hardness (°F)		50.0	54.1	43.2	59.8	60.5	55.6
Na^{+}	mg/l	848.8	2111.8	1602.4	1521.1	1369.9	900.4
K^{+}	mg/l	16.5	27.1	19.2	6.1	22.1	21.4
Ca^{++}	mg/l	71.1	39.8	27.4	80.2	48.5	50.9
Mg^{++}	mg/l	78.4	105.1	90.7	101.0	115.4	94.4
NH_4^{+}	mg/l	0.1	0.1	0.2	0.0	0.0	0.0
Cl^{-}	mg/l	1063.4	2333.1	1825.4	1825.5	1690.4	1111.3
SO_4^{--}	mg/l	601.2	1003.9	500.7	1213.3	1069.9	869.6
NO_3^{-}	mg/l	4.7	4.2	1.3	6.9	7.0	3.8
NO_2^{-}	mg/l	0.0	0.0	0.0	0.0	0.0	0.0
HCO_3^{-}	mg/l	589.9	762.7	778.4	720.5	753.5	620.0
PO_4^{---}	mg/l	2.3	2.5	2.1	3.3	2.6	1.9
F^{-}	μg/l	710	1030	990	-	1020	990

- : not measured.

Shading indicates the concentrations which are higher than the maximum permitted levels by Hellenic Legislation for potable water (HGN, 2001).

IV.B. Groundwater

The water chemistry of the phreatic (shallow) and the deep aquifer (Table 6) is not significantly different, except for K, Mg, Ca and F. This justifies our data supporting that there is a slow water circulation between the two different

Table 6. Water quality in the phreatic (shallow) and the deep aquifer.

Sample No		1	2	3*	4*
pH		8.17	7.99	7.74	7.67
E.C. (μS/cm)		1040	1106	890	625
Na^{+}	mg/l	100.0	175.9	120.0	106.0
K^{+}	mg/l	1.6	1.2	4.0	4.0
Ca^{++}	mg/l	82.0	83.3	64.0	28.8
Mg^{++}	mg/l	55.9	44.7	20.9	12.3
NH_4^{+}	mg/l	0.0	0.1	0.2	0.1
Cl^{-}	mg/l	138.3	141.5	85.1	81.6
SO_4^{--}	mg/l	43.0	45.2	52.1	24.5
NO_3^{-}	mg/l	11.9	3.7	9.6	0.5
NO_2^{-}	mg/l	0.0	0.0	0.0	0.0
HCO_3^{-}	mg/l	477.0	594.3	398.9	247.7
PO_4^{---}	mg/l	-	-	0.3	0.6
F^{-}	μg/l	-	-	1610	700

- : not measured. Analyses from: 1 and 2: shallow; 3 and 4: deep aquifer.

Shading indicates the concentrations which are higher than the maximum permitted levels by Hellenic Legislation for potable water(HGN, 2001).

*: Unpublished data of Veranis and Katirtzoglou (2002).

aquifers. The increase in K and F contents in the deep aquifer indicate a water influx from the underlying geothermal field to the deep water aquifer (Lohnert et al., 1992; Poutoukis and Ntotsika, 1994; Michailidis et al., 2000; Nimfopoulos et al., 2002). The elements Ca and Mg originate from the geological environment.

V. CONCLUSIONS

The gradual decline in the volume of the surface and groundwater, combined with the increasing contribution of urban and industrial pollutants to quality degradation of stream water and groundwater, has led to the present disappointing environmental conditions in Lake Koronia.

The Mygdonia basin problem cannot be solved only by water transport from the Aliakmon or the Strymon rivers, unless a rational management with environmental, economic and social parameters is applied. Otherwise, the ecosystem will collapse again under the pressure of catastrophic anthropogenic impact.

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