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ORIGINAL ARTICLE

Assessment of the quality characteristics of two lakes (Koronia and Volvi) of N. Greece

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Abstract Quality parameters from 17 sampling stations from Lake Koronia and 18 from Lake Volvi were determined during sampling period of one year. Physicochemical parameters (pH, conductivity, DO) did not show remarkable differences neither between sampling sites nor between sampling periods. Nutrient concentrations (nitrogen and phosphorus compounds) were higher in lake Koronia than in Volvi showing relatively small temporal and spatial variations. As far as heavy metals in sediments, lake Koronia is considerably more polluted than Volvi lake especially with the metals Fe, Mn, Zn, Pb and Cd. The mean total concentrations of metals in lake Koronia decrease in the order Mn > Zn > Cr > Pb > Cu > Fe > Cd. The mean total concentrations of metals in lake Volvi decrease in the order Mn > Zn > Cr > Cu > Pb > Fe > Cd.

Keywords Lake sediments · Water · Heavy metals · Nutrients · Physicochemical parameters

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1 Introduction

Anthropogenic impact on natural environments and especially on aquatic ecosystems is currently a topic of increasing concern. Deterioration of surface water and especially Lake water quality has recently observed in many aquatories. The potential causes of such a situation are various point source pollution (domestic and industrial effluents) can be localized and well-established, whereas the influence of non-point pollution (runoff from intensively cultivated areas and urban centres) is less obvious because of the inadequately defined direction and frequency of non-point source loading. Most of those activities lead to the pollution of lakes. The quality of lake water may vary depending on the geological morphology, vegetation and activities in the catchment basin, as well as on the location of the sampling site. In Europe, pollutants of domestic, industrial and agricultural origin have seriously degraded the lake quality during the last centuries, especially after the industrial revolution. The introduction of large quantities of nutrients, mainly nitrogen and phosphorus to lake waters can cause eutrophication problems (Michelutti *et al.*, 2002; Kouimtzis *et al.*, 1994; Fytianos *et al.*, 2002). Nitrates devire from agricultural sources and, unlike phosphorus, which is absorbed by soils, it is, in part, washed from the land during storm events.

In Greece, both point and non-point pollution sources contribute to the deterioration of river water quality. Until recently, few domestic waste-water treatment plants were in operation in Greece and consequently, in many cases, urban effluents are still being discharged untreated to the neighbouring watercourses (Andrearakis and Katsara, 1995; Fytianos and Lourantou, 2004). On the other hand, because agriculture represents a major activity in Greece (with extensive use of fertilizers and pesticides), agricultural land runoff also plays a very important role in the degradation of the surface water quality, especially in the region of Macedonia, which is the largest plain with such an agricultural production in Greece.

To prevent the adverse environmental effects of development onto a lake system and its catchment area, the implication of an integrated environmental management plan is considered as the most effective approach to ensure sustainable use of water resources and protection of river water quality.

In the frame of the present work, a study was performed for the area of Northern Greece (Macedonia), aiming at the control and management of the Lakes Volvi and Koronia in this area (Fytianos and Lourantou, 2004). This study can also provide an important base for the development of national strategies for aquatic environmental management. The results of this study are presented here.

2 Materials and methods

2.1 Study area

The studied lakes, Volvi and Koronia, are located in N. Greece, about 11.5 km NE of Thessaloniki (Fig. 1). The whole area is protected by the Ramsar Convention, as a site of international importance for the value of the wetland habitat. The wetland includes important natural complex habitat types such as fresh water marsh, lacustrine and riverine forests, scrublands, as well as agricultural landscapes. The area provides an ideal habitat for a variety of flora and fauna species. It is a significant habitat of structural and species diversity (fish, invertebrates, reptiles, birds, mammals), also providing an important nesting and roosting site for many endangered bird species. Both lakes are mainly recharged by rainfall, surface and ground water as well as by thermal springs. The major sources that affect the water quality and the trophic status of the lakes are agricultural runoff, animal husbandry effluents and industries. Other important sources are resuspende stream sediments and erodes bank materials.

Volvi is an elliptic-shaped lake with surface area 69 km^2 and mean depth 13.5 m. The maximum depth

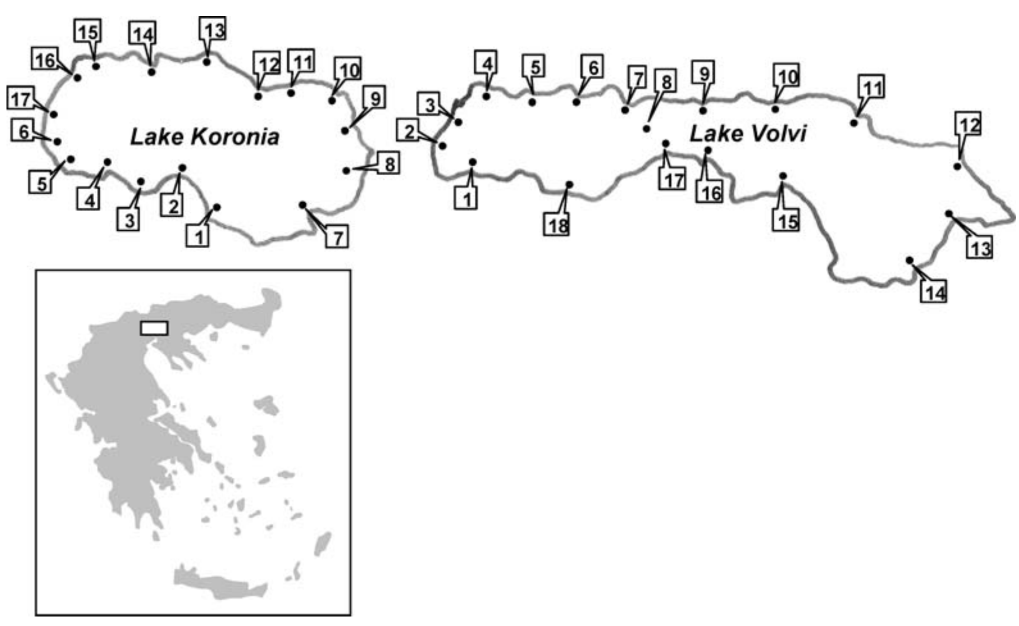


Fig. 1 Map of the studied area with the sampling sites

(∼ 24 m) is observed in the east part. Small rivers and streams transport significant quantities of particulate matter in the E-SE part of the lake resulting in a reduction of the surface area. During water stratification, starting at the beginning of summer, anoxic conditions are observed in the bottom, mainly in the deep east part of the lake. The lake has been classified on the basis of chemical and biological water parameters, as meso-to-eutrophic lake.

Koronia is an elliptic-shaped shallow lake with a mean depth ∼2 m and a surface area 42 km^2. The surface area has been significantly shrunk during last 20 years (by about 0.6% per year) due to overexploitation of water for agricultural and industrial purposes and the transportation of particulate matter from small stream inflows, mainly in the west part of the lake. Moreover, the water quality has deteriorated and the lake has been classified as hypertrophic. The nutrient enrichment of the lake has seriously degraded the aquatic ecosystem and led to diverse problems such as toxic algal blooms, low transparency, severe depletion of dissolved oxygen, fish kills, loss of biodiversity etc. Because of its low depth, winds disturb the sediment occasionally.

This monitoring study was carried out with water and sediment samples from the two lakes, Koronia and Volvi. The water and sediment samples were collected every three months, from June 2000 to March 2001. Seventeen sampling sites for Koronia and eighteen for Volvi lake were established.

For water sampling, 1 L bottles were used, and the collected water samples were filtered through 0.45 μm glass fibre filter (Whatman) to eliminate particulate matter (Standard Methods, 1995).

Sediment samples were collected using an Eckman sampling device from the lake Koronia and from the lake Volvi. Samples taken were immediately taken to the laboratory and air-dried. Then stones and plant fragments were removed by passing the dried sample through a 2-mm sieve. The sieved sample was powdered and finally passed through a 75-μm sieve (silt/clay fraction) and stored in glass bottles (Coale and Flegal, 1998; Belzile and Dixit, 2004; Fytianos *et al.*, 1986).

Analysis of the fraction <75 μm is recommended in sediment studies because clay and silt particles generally contain the highest concentrations of pollutants, and are most readily transported is suspension in natural waters.

Analytical reagent-grade solutions were used without further purification. The sequential leaching procedure was carried out with three replicates. The flame atomic absorption spectrometry (FAAS) was used for the determination of Fe, Mn while Zn, Cu, Pb, Cd and Cr were determined by Electothermal Atomic Absorption Spectrometry (ETAAS) with a Perkin-Elmer 2380 atomic absorption spectrometer equipped with an HGA 400 furnace programmer.

The precision of the metal analysis was controlled by including triplicate samples in analytical batches, blanks and the method of standard additions. The relative standard deviations of means of triplicate measurements were less than 5% which was regarded as a satisfactory precision. The results are expressed as a dry weight basis. The analytical procedure for the determination of total concentrations was checked by means of analysis of certified material of lake sediment (CRM 280, BCR).

For the determination of heavy metals associated (chelated or adsorbed) with humic and fulvic acids, the sediments were treated with 0.1 N NaOH for 10 h. Leaching with 0.1 N HCl has also been used for the evaluation of the pollution of the areas examined. This extraction removes the "anthropogenic" trace element fraction from the sediment.

3 Results and discussion

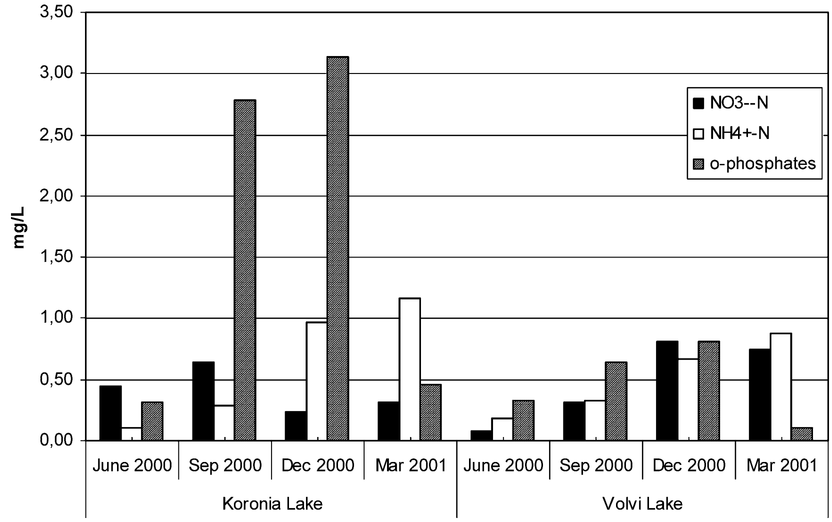
The temporal and spatial distribution of same parameters determined in the water of Koronia and Volvi Lakes is shown in Tables 2 and 3 while the mean values of the chemical parameters for each lake are given in Table 1.

The pH values did not show remarkable differences neither between sampling sites, nor between sampling periods and the values for each lake ranged from 8.8 to 9.1 for Koronia and from 8.4 to 8.7 for Volvi respectively. The water of the lake Koronia, because of its high pH values is not suitable for irrigation.

Conductivity showed temporal variation ranging between 476 and 932 for Koronia and between 890 and 1150 $\mu S/cm^2$ for Volvi.

Sulphates showed remarkable seasonal variations at the most sampling sites in Koronia with higher concentrations being recorded during September and at sampling sites 4, 11 and 14 (1440–1620 mg/l) while at the other sites the fluctuation was smaller (140–380 mg/l). In the lake Volvi, sulphate showed a lower variability

Fig. 2 Mean Concentrations of nutrients



(12–134 mg/l), that is indicative of the homogenisation influence of the lake. Sulphate spatial pollution varies widely according to point source pollution sites.

Concerning the mean concentration of nutrients, their mean concentrations for all sites for each lake are given in Table 1.

The mean nitrate concentrations for Koronia were rather low, ranging from 0.23 to 0.64 mg N/l and for Volvi were higher ranging from 0.08 to 0.81 mg N/l.

Moreover, the low nitrate concentrations were observed during summer and every autumn, before the wet period.

Similar pattern was also observed for NH_4-N and ranging for Koronia from 0.10 to 1.16 mg/l and for Volvi between 0.18 and 0.88 mg/l.

The mean concentrations of total N ranged between 9.1 and 14.3 mg N/l for Koronia and between 1.8 and 3.1 mg N/l for Volvi depending on variations of NO_3^- concentrations mainly. Highest total N values were observed at sampling sites 9, 15 and 17 for Koronia and 5, 10 and 15 for Volvi.

These sites showed elevated NO_3^- concentrations during all samplings and particularly after heavy rainfalls as a result of highest inflows reaching the lakes from the surrounding agricultural areas.

The chemistry of phosphates is extremely complicated in the natural environment and interpretation of the results is very difficult. Phosphates in natural runoff are greatly increased by the decay of vegetable matter, which may be observed onto the particulate matter. The

Table 1 Main characteristics of the studied lakes

	Lake Koronia	Lake Volvi
Surface area (km^2)	42	69
Mean depth (range) (m)	2 (1–4)	13.5 (10–24)
Altitude (m)	75	37
Natural trophic status	Mesotrophic level	Lower Mesotrophic level
Ph	0009.2 (8.73–9.54)	0008.87 (8.43–9.14)
Conductivity (μS/cm)	5720 (4650–9280)	1045 (890–1150)
DO (mg/l)	0007.8 (6.8–8.2)	0008.1 (6.3–10.4)
COD (mg/l)	0161 (84–242)	0084 (42–132)
TOC (mg/l)	0017.2 (6.8–38.4)	0016.3 (8.0–29.3)
TC (mg/l)	0105.6 (73–142)	0094.5 (60–126)
IC (mg/l)	0195 (65–293)	0078.26 (42–116)
TP (μg N/l)	0362 (96–456)	0155 (64–218)
NO_3 (μg N/l)	0182 (49–329)	0102 (16–206)
NO_2 (μg N/l)	0027 (12–41)	0024 (10–32)

Table 2 Mean total content (mg/g dw) of heavy metals in sediments and partitioning range (%) of heavy metals associated with humic and fulvic acids and the "anthropogenic" fraction

	Pb		Zn		Cu		Mn		Fe		Cr		Cd	
Lake Koronia														
Total (mg/g dw)	20.38	(16.30–24.46)	85.86	(72.12–99.60)	16.76	(14.76–18.77)	631.80	(581.3–682.3)	5.46	(5.24–5.68)	32.20	(27.27–37.03)	0.99	(0.97–1.01)
Anthropogenic (%)	55.45	(50.45–60.45)	42.94	(37.84–48.04)	41.25	(37.60–45.10)	51.95	(47.05–56.85)	30.47	(28.27–32.67)	20.86	(17.66–23.06)	63.02	(61.05–64.99)
Humic (%)	10.09	(9.59–10.59)	4.38	(4.07–4.69)	1.88	(1.66–2.10)	0.24	(0.21–0.27)	1.97	(1.79-2.15)	3.32	(2.77–3.87)	5.19	(4.31–6.07)
Lake Volvi														
Total (mg/g dw)	12.46	(10.52–14.40)	53.43	(47.93–58.93)	15.20	(14.00–16.22)	145.30	(133.4–157.23)	3.65	(3.53–3.77)	23.12	(20.92–25.32)	0.75	(0.74–0.76)
Anthropogenic (%)	46.32	(41.32–51.32)	37.85	(35.01–40.69)	46.90	(45.02–48.78)	17.05	(16.54–17.56)	27.22	(26.29–28.15)	23.45	(12.78–14.12)	48.40	(45.45–51.35)
Humic (%)	12.28	(11.89–12.67)	7.84	(7.62–8.06)	12.09	(11.68–12.50)	1.56	(1.53–1.59)	3.67	(3.56–3.78)	4.02	(3.86–4.18)	3.15	(3.04–3.26)

Table 3 Mean total concentrations of chemical parameters in water samples

	pH		Conductivity (μS/cm^2)		SO_4^- (mg/L)		NO_3^--N (mg/L)		NH_4^+-N (mg/L)		TN (mg/L)		$PO4^{3-}$ (mg/L)	
Lake Koronia														
June 2000	9.1	(8.9–9.2)	476	(415–534)	564	(438–654)	0.44	(0.1–0.67)	0.10	(0.05–0.15)	14.3	(12.9–16.3)	0.31	(0.09–0.92)
Sep 2000	8.8	(8.6–8.9)	932	(890–945)	965	(565–1620)	0.64	(0.2–0.96)	0.29	(0.21–0.36)	9.1	(8.8–9.2)	2.78	(1.42–5.14)
Dec 2000	8.8	(8.5–8.8)	915	(895–935)	670	(430–714)	0.23	(0.16–0.57)	0.96	(0.33–3.75)	13.2	(12.8–13.6)	3.14	(2.73–3.63)
Mar 2001	9.1	(9.0–9.2)	525	(515–550)	517	(495–527)	0.31	(0.15–0.58)	1.16	(0.87–4.95)	11.2	(7.9–14.6)	0.46	(0.12–0.89)
Lake Volvi														
June 2000	8.7	(8.4–8.9)	890	(878–898)	87	(56–93)	0.08	(0.04–0.14)	0.18	(0.15–0.25)	2.4	(1.1–5.5)	0.32	(0.12–0.65)
Sep 2000	8.7	(8.6–8.7)	1150	(1135–1157)	134	(99–145)	0.31	(0.23–0.43)	0.32	(0.28–0.35)	1.8	(1.7–2.1)	0.64	(0.46–0.99)
Dec 2000	8.5	(8.4–8.6)	965	(958–976)	68	(58–74)	0.81	(0.78–0.97)	0.67	(0.31–0.81)	2.1	(1.4–2.8)	0.81	(0.46–1.34)
Mar 2001	8.4	(8.3–8.5)	914	(910–919)	66	(58–72)	0.74	(0.65–0.89)	0.88	(0.70–1.48)	3.1	(2.1–5.6)	0.11	(0.05–0.55)

phosphorus content of a water body is mainly affected by the natural characteristics of the drainage basin (morphometry and edaphic factors) and the anthropogenic nutrients inputs (Rydin, 2000).

Orthophosphates in Koronia lake were generally found at concentration levels between 0.31 and 3.14 and in Volvi between 0.11 and 0.81. Concerning phosphates, Koronia lake and more polluted than Volvi. The highest values were found at sampling site 15 for Koronia and 11 for Volvi.

Phosphates concentrations were low in Volvi lake showing relatively small temporal and spatial variations, that were attributed to agricultural and municipal activities.

Comparing the total concentrations of heavy metals in sediments between Koronia and Volvi lakes (Table 2), we conclude that metal pollution in sediments of the Koronia Lake is considerably higher. No significant differences in heavy metal concentrations were observed in the sediments form all the stations in Lake Volvi and Koronia, suggesting influence from geological factors rather than from point sources.

The mean total concentrations of metals in Koronia decrease in the order Mn $>$ Zn $>$ Cr $>$ Pb $>$ Cu $>$ Fe $>$ Cd, while for Lake Volvi the order is Mn $>$ Zn $>$ Cr $>$ Cu $>$ Pb $>$ Fe $>$ Cd.

The above mentioned order shows an increased Cr and Zn participation in the soil metal content which could possible be attributed to anthropogenic pollution.

The anthropogenic mean concentration heavy metals in sediments follow the order:

Cd $>$ Pb $>$ Mn $>$ Zn $>$ Cu $>$ Fe $>$ Cr for Koronia Lake and Cd $\geq$ Pb $\simeq$ Cu $>$ Zn $>$ Fe $\simeq$ Cr $>$ Mn for Volvi Lake

Conclusions

Quality parameters were determined in the water of Volvi and Koronia Lake during sampling period of one year. Physicochemical parameters (pH, conductivity, DO) did not show remarkable differences neither between sampling sites nor between sampling periods. Nutrient concentrations (nitrogen and phosphorus compounds) were higher in Koronia lake than in Volvi showing relatively small temporal and spatial variations, that were attributed to agricultural and municipal activities (EC Council Directive, 1998).

Concerning the total concentrations of heavy metals in sediments, Koronia lake is considerably more polluted than Volvi lake especially with the metals Fe, Mn, Zn, Pb and Cd.

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