Scientific Paper

PHYSICO–CHEMICAL CHARACTERISTICS OF LAKE WATER IN 14 SLOVENIAN MOUNTAIN LAKES

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Abstract

Basic physical and chemical characteristics of the water in 14 Slovenian mountain lakes were determined. Surface water was sampled once a year over three consecutive years (2000-2002). The influences of lake and catchment area properties on the measured parameters were studied. The lake's trophic status and size of catchment area were found to affect the water chemistry. Pearson correlation coefficients were calculated to identify the strength of relation between the variables. The highest correlation was found among the alkalinity, calcium and conductivity. Cluster analysis was additionally performed to obtain natural groupings in the data. Finally, the condition of the lakes was assessed. Although the water quality has deteriorated in some lakes (especially in Jezero na Planini pri Jezeru), most of the lakes are still in a good condition.

Key words: water chemistry, alpine lakes, Julian Alps

Introduction

Mountain lakes are situated in remote areas that are usually far away from local sources of pollution and anthropogenic influence. Although accessible with difficulty, they have received, especially lately, substantial scientific attention from research groups studying physical, chemical, biological and hydrological processes in their water columns, sediments and catchment areas. One of the key issues of interest is that these lakes can be used as reliable sensors of environmental change.[1] In general, mountain lakes are small and have rapid flushing rates. As a consequence, they respond rapidly and strongly to any direct anthropogenic influence or change in their catchment areas. Several research projects on a European scale have been initiated in the last decades to investigate mountain lakes and to improve our understanding of these lake systems.[1,2,3]

All Slovenian mountain lakes are located in the Julian Alps, which lie in the NW part of Slovenia. Their geographical position is shown in Figure 1, and their topographical characteristics are summarized in Table 1. The lakes can be divided geographically into three distinct groups (Figure 1). The northernmost group is located at Kriški podi and the 3 lakes of this group are called the Kriško lakes. The 8 lakes of the central group are located in the Valley of the seven lakes of Triglav and are called the Triglav lakes. The southernmost group includes 3 lakes called the Krn lakes. All the lakes are located at elevations from 1325 to 2150 m, mostly above the tree line of approximately 1800 m, but 6 lakes, Peto jezero, Šesto jezero, Črno jezero, Jezero na Planini pri Jezeru, Krnsko jezero and Dupeljsko jezero, below the tree level. All the lakes are of glacial origin and are small and shallow. Their surface areas extend from 0.25 to 4.53 ha, while their maximal depths range from 3 to 18 m (Table 1). However, most of the lakes have a surface area of 0.5-1 ha, are approximately 7-10 m deep and are surrounded by steep slopes.

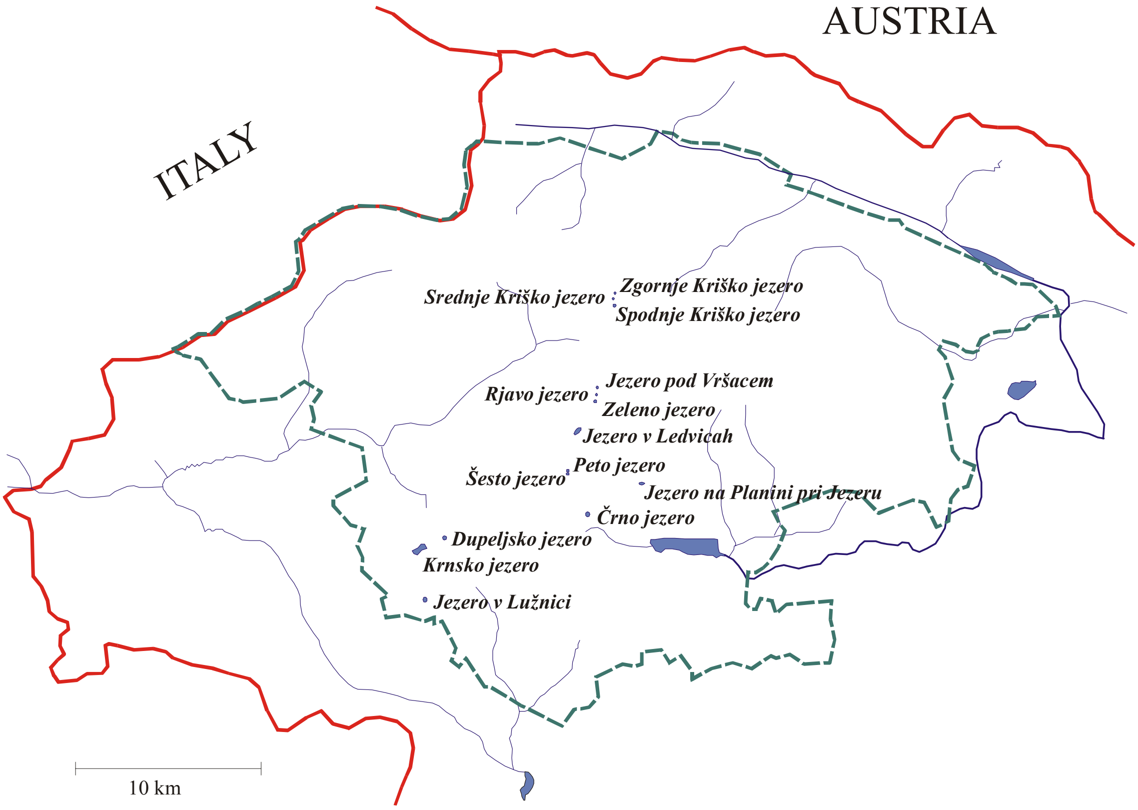


Figure 1. Geographical position of Slovenian mountain lakes.

They are normally covered with ice for long periods of the year. Ice cover periods as short as five and as long as nine months per year (Zgornje Kriško jezero) have been observed in the Julian Alps.[4] The annual precipitation rate is high, ranging from 2600 to over 3200 mm per year.[5] Atmospheric deposition is thus important for these lakes, since

Table 1. Topographical characteristics of the Slovenian mountain lakes.[4]

	Altitude [m]	Surf. Area [ha]	Max. Depth [m]	Catchment [ha]
Jezero pod Vršacem (1J)	1993	0.56	7	54
Rjavo jezero (2J)	2002	1.34	10	36
Zeleno jezero (3J)	1983	0.61	3	24
Jezero v Ledvicah (4J)	1830	2.19	15	175
Peto jezero (5J)	1669	1.00	11	90
Šesto jezero (6J)	1669	0.66	9	90
Črno jezero (7J)	1325	0.86	9	140
J. na Planini pri Jezeru (PJ)	1430	1.56	11	95
Zgornje Kriško jezero (ZgKJ)	2150	0.66	9	16
Srednje Kriško jezero (SrKJ)	1950	0.29	9	26
Spodnje Kriško jezero (SpKJ)	1880	0.87	9	13
Krnsko jezero (KJ)	1383	4.53	18	550
Dupeljsko jezero (DJ)	1340	0.25	3	46
Jezero v Lužnici (JL)	1800	0.47	10	66

they have mostly no permanent surface inflows. Nevertheless, only slight fluctuations of water levels were observed in the lakes, averaging 1 m. The bedrock in the areas where the lakes are situated, consists primarily of Triassic limestones and dolomites.[6,7] Nevertheless, there are some areas with more diverse geology. In the Valley of the seven lakes of Triglav, Jurassic limestones with inclusions of manganese-pyrite crusts can be found, while the geology of Jezero v Lužnici includes Jurassic and Cretaceous limestones and also marl-limestones. The area of the Triglav National Park (TNP), where all the lakes are situated, is protected by law. Thus, any human impact on the lakes is reduced. Most lakes are therefore still in a pristine condition. Some, however, are more affected by anthropogenic influence, resulting in deteriorated conditions.[8] These lakes are mostly located close to mountain huts and include Jezero na Planini pri Jezeru and Krnsko jezero.

In 2000, the project EMERGE on the condition of European mountain lakes was initiated. Within this project, all 14 Slovenian mountain lakes were studied and several chemical, physical and biological analyses were performed on their water columns, sediments and catchment areas. Water chemistry was one of the parameters studied. In general, it is controlled by rock weathering, but it can be further affected by atmospheric deposition processes, evaporation/crystallization and biological activity in the water column.[9,10,11]

The main purpose of this paper is to present basic chemical and physical characteristics of lake water in the 14 Slovenian mountain lakes. The alkalinity, nitrate, sulfate, chloride, nitrite, phosphate, pH, and calcium, magnesium, sodium, potassium, ammonium, total nitrogen (TN) and total phosphorus (TP) concentrations, as well as temperature, conductivity and oxygen concentration/saturation were determined in the surface water layers during 2000-2002. In addition, the data were analyzed statistically to identify the strength of relationship between the variables and natural groupings in the data itself. Since all Slovenian mountain lakes were studied during the three consecutive years, it was possible to examine changes of parameters among the lakes due to differences in the lakes' trophic status, exposure to anthropogenic influence, and other parameters such as biological activity in the water column and hydrology. Limnological studies of Slovenian mountain lakes are rare, only a few studies on water chemistry having been reported.[e.g. 4,8] The present paper thus complements our knowledge on the basic water chemistry of these vulnerable lakes.

Experimental

Sampling

All the lakes were sampled once per year in late August/early September, during the time of summer stratification. The samples therefore represent only a "snapshot" of limnological conditions. Water samples were taken from the deepest part of the lakes using a Van Dorn sampling device (Wildco, USA). They were filtered through a 0.2 μm filter (Fluropore membrane filters, Millipore) to eliminate solid particles and reduce biological activity. Plastic containers (PP, Brand) were used to store samples. Conductivity, oxygen concentration/saturation and temperature were measured in the field using a WTW Multiline P4 universal instrument. Samples were delivered to the laboratory as soon as possible, at latest one day after collection, and analyzed immediately after arrival at the laboratory.

Chemical analyses

Standard laboratory procedures were followed for analyses of water samples, according to APHA *et al.*[12] A detailed description is described elsewhere.[8] Briefly, the pH was measured with a digital WTW pH 540 GLP instrument, using a SenTix 81 glass electrode and calibrated with buffers of pH 4.01, 7.0 and 10.0. Alkalinity was determined by the Gran titration method.[12] TN and TP were analyzed after oxidation of water samples with persulfate and subsequent spectrophotometric determination of the nitrate and ortho-phosphate concentrations in the digestates,[12] using a UV-VIS spectrophotometer (Lambda 12, Perkin Elmer). Major anions and cations were determined with an ion chromatograph[12] (761 Compact IC, Metrohm) equipped with conductivity detection cell. Chloride, nitrite, nitrate, phosphate and sulfate were analyzed using a METROSEP A Supp 5 separation column (150 × 4.0 mm), and sodium, ammonium, potassium, calcium and magnesium were determined on a METROSEP C_2 150 separation column (150 × 4.0 mm). A chemical suppressor module was used when determining anions, but not in the case of cation analysis. Detection limits of ions were in the range 30-50 μg/L.

Standard solutions and blank samples were used to calibrate the instruments and check the calibration curves. Analytical results were validated using the calculations and controls proposed by APHA *et al.*[12] Once the sample analyses have been completed, an ion balance was calculated as a further check on the data quality. Differences between the total anions and total cations were within 5-10%.

Statistical analyses

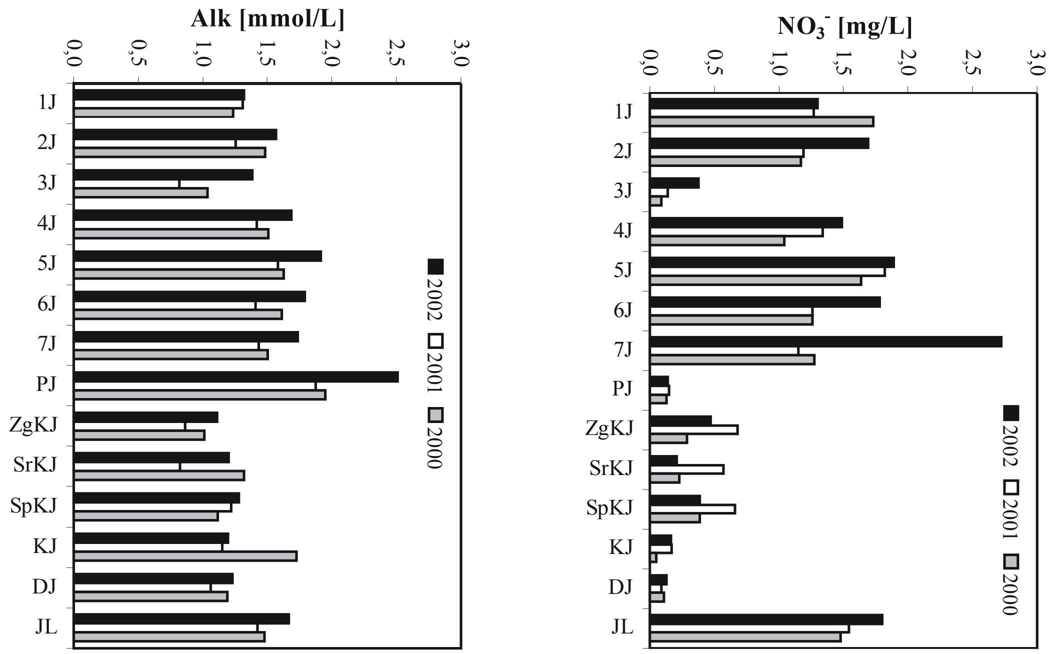
The measured parameters varied over the years. The arithmetic means of each parameter were therefore calculated for each lake to obtain representative values for use in statistical analyses. The strength of relation between variables was ascertained using a Pearson correlation matrix of the data. Cluster analysis was also applied to the data to facilitate an overview of the variables and lakes and how they group. In cluster analysis, natural groupings in the data itself are identified without taking into account any prior knowledge of the samples.[13] Before cluster analysis, all values were standardized, i.e. the data were transformed to the data with a mean of zero and a standard deviation of 1. A hierarchical single linkage method was then applied, where nearest neighbors are step by step agglomerated into clusters, as measured by Euclidean distances.

Results and discussion

Water chemistry

Hydrogen carbonate/carbonate were the most abundant anions in the lakes, contributing over 90% of the total anion concentration. They also accounted for the high alkalinity which generally averaged 1.5 mmol/L (Figure 2). The highest value was observed in Jezero na Planini pri Jezeru, exceeding 1.9 mmol/L. Lower values were observed in the Kriško lakes, Zeleno, Dupeljsko and Krnsko jezero, where the alkalinity was normally lower than 1.2 mmol/L.

Nitrate concentrations mostly ranged from 1 to 2 mg/L (Figure 3). In the Kriško lakes, the concentrations were lower and averaged 0.5 mg/L. Lower nitrate concentrations were also observed in the productive lakes, Zeleno jezero, Jezero na Planini pri Jezeru, Krnsko and Dupeljsko jezero. In these lakes, nitrate concentration dropped as low as 0.05 mg/L.



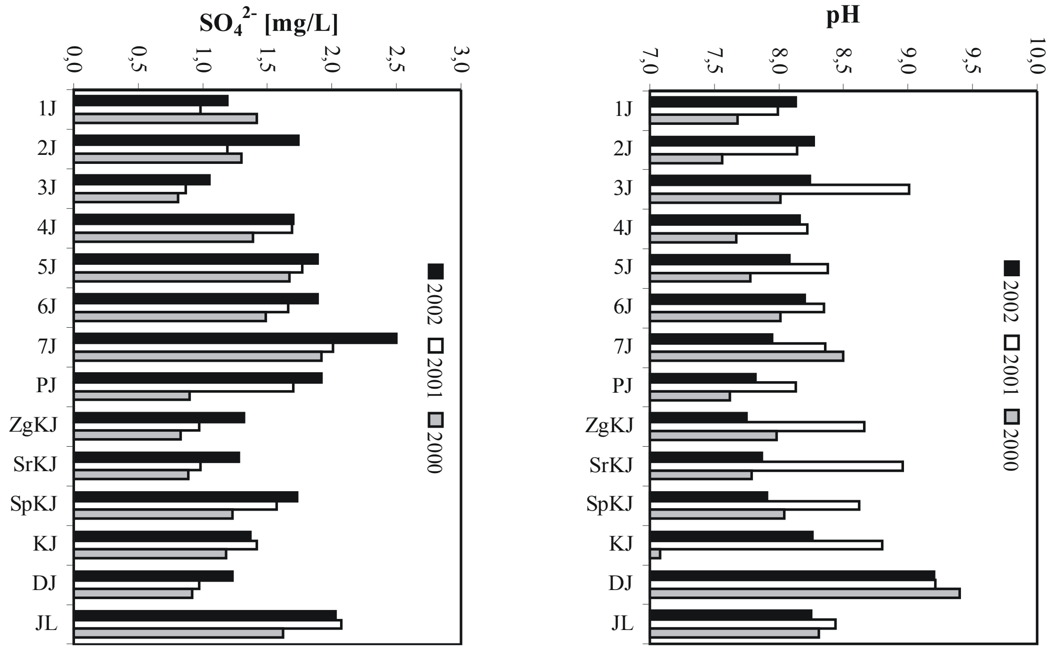
Figures 2 and 3. The alkalinity (Alk) and nitrate concentration in the surface waters of the lakes in the three consecutive years (2000-2002) (see Table 1 for lake abbreviations).

In most lakes, sulfate concentrations ranged from 1 to 2 mg/L (Figure 4). Lower concentrations up to 1 mg/L were observed in Zeleno jezero, the Kriško lakes and Dupejsko jezero, while the highest concentration of approximately 2 mg/L was observed in Črno jezero and Jezero v Lužnici.

Chloride concentration was quite low and uniform in the lakes and ranged from 0.2 to 0.8 mg/L.

Nitrite and phosphate concentrations were below the limits of detection (0.05 mg/L) in all the lakes.

In most lakes, the pH ranged from 7.5 to 8.5 (Figure 5). Nevertheless, pH values as low as 7.1 and as high as 9.4 were observed. The highest pH value was observed in Dupeljsko jezero, while the lowest values were observed in Jezero na Planini pri Jezeru.



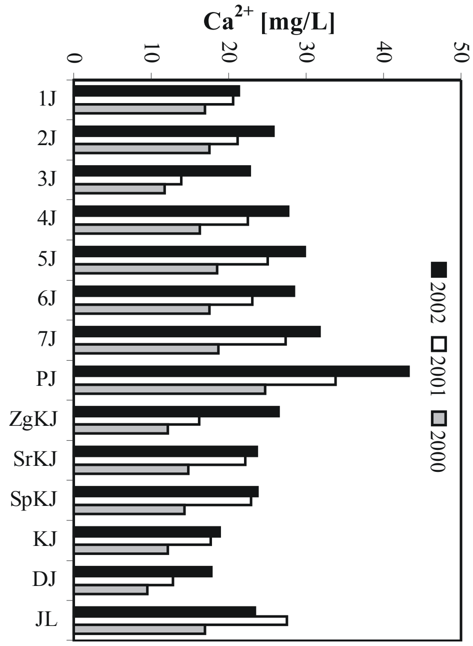
Figures 4 and 5. Sulfate concentration and pH in the surface waters of the lakes in the three consecutive years (2000-2002) (see Table 1 for lake abbreviations).

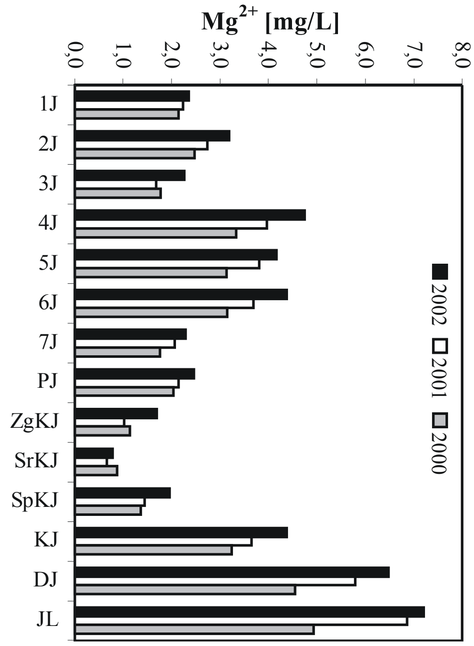
Calcium was the most abundant cation. It constituted over 90% of the total cation concentration, but varied considerably in the lakes, ranging from 10 to 45 mg/L (Figure 6). In most lakes, however, it averaged 25 mg/L. The lowest calcium concentration was observed in Dupeljsko jezero, dropping to as low as 9.5 mg/L. Low concentrations, ranging from 12 to 25 mg/L were also observed in the Kriško lakes, Zeleno and Krnsko jezero. Calcium concentrations were the highest in Jezero na Planini pri Jezeru and exceeded 30 mg/L.

Magnesium concentration also varied considerably. It generally ranged from 2 to 5 mg/L (Figure 7) but the lowest concentration of around 1 mg/L was observed in the Kriško lakes, and the highest in the Krn lakes, where it ranged from 3.5 to 7.2 mg/L.

Quite low sodium concentrations were observed in the lakes. They normally ranged from 0.5 to 1 mg/L, only rarely exceeding 1 mg/L. Potassium concentration was uniform in the lakes and averaged 0.5 mg/L.

Ammonium concentration was mostly below the detection limit of 0.05 mg/L. Nevertheless, in some productive lakes, i.e. Jezero na Planini pri Jezeru, Dupeljsko and Zeleno jezero, low concentrations of up to 0.1 mg/L were observed.



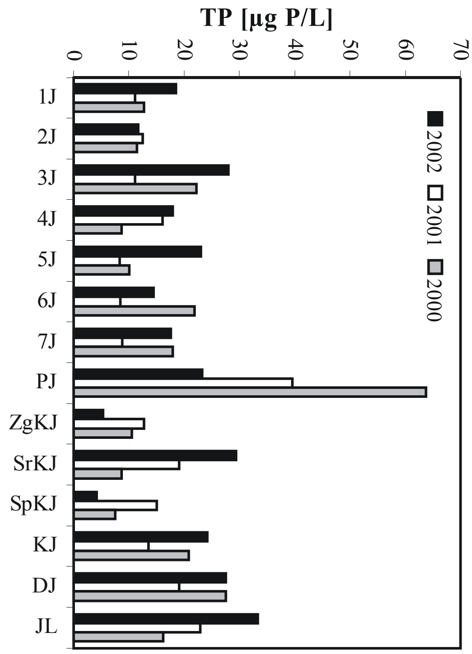


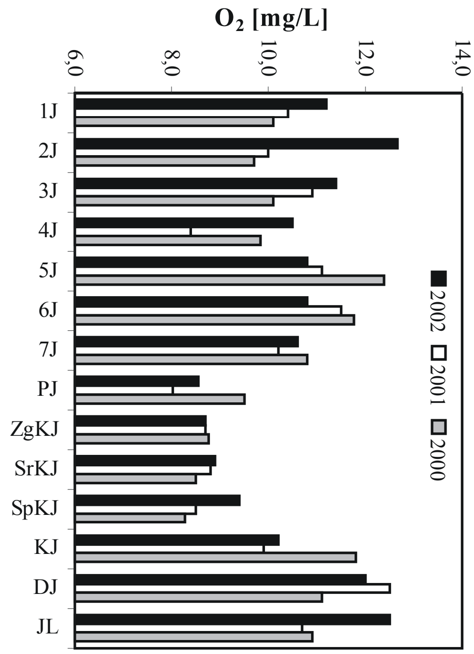
Figures 6 and 7. Calcium and magnesium concentration in the surface waters of the lakes in the three consecutive years (2000-2002) (see Table 1 for lake abbreviations).

A fairly uniform distribution of TN was observed, ranging from 1.4 to 2.2 mg N/L.

In most lakes, TP varied from 10 to 20 µg P/L (Figure 8). However, this range was regularly exceeded in the more productive lakes, such as Jezero na Planini pri Jezeru, Krnsko jezero, Dupeljsko jezero and Zeleno jezero, and occasionally in Jezero v Lužnici and Srednje Kriško jezero. In these lakes, TP concentration was as high as 64 µg P/L.

Dissolved oxygen concentration in the surface waters was high, exceeding 8.5 mg/L in all the lakes (Figure 9). These water layers were thus well oxygenated, with oxygen saturation ranging from 100 to 135%. The lowest oxygen saturation was observed in Jezero na Planini pri Jezeru, dropping to 90% on some occasions. In contrast, oxygen saturation of up to 135% was observed in the shallow, productive lakes, such as Dupeljsko jezero and Zeleno jezero.





Figures 8 and 9. Total phosphorus (TP) and dissolved oxygen concentration in the surface waters of the lakes in the three consecutive years (2000-2002) (see Table 1 for lake abbreviations).

Physical parameters

A wide range of temperature was observed in the lakes. Higher temperatures were observed in those situated at lower altitudes, and vice versa. Thus, the highest temperatures were observed in Dupeljsko jezero and Jezero na Planini pri Jezeru, reaching 20 °C. In contrast, the temperature in Jezero pod Vršacem, the coldest lake, did not exceed 9 °C. Seasonal[4] and daily temperature variations[14] were observed. Even the daily variations were substantial, as shown in the study on the Kriško lakes.[14] Surface water temperature of these lakes changed by up to 4 °C in a day, reflecting current meteorological conditions.

The water conductivity was more uniform. It averaged 150 µS/cm in most lakes (Figure 10). Lower values were observed in the Kriško lakes, Zeleno, Krnsko and Dupeljsko jezero, averaging 100 µS/cm. Low conductivity indicates a low total concentration of dissolved ions.[9,10] The Kriško lakes have small catchment areas. As a consequence, weathering of bedrock and surface run-off were low and so was the total concentration of dissolved ions. In the productive lakes, Zeleno, Krnsko and Dupeljsko jezero, the low total concentration of dissolved ions resulted from precipitation of calcium carbonate in the surface waters. The highest conductivity was in contrast observed in the highly productive Jezero na Planini pri Jezeru, exceeding 180 μS/cm, and resulted, most probably, from dissolution of calcium carbonate in the surface water.

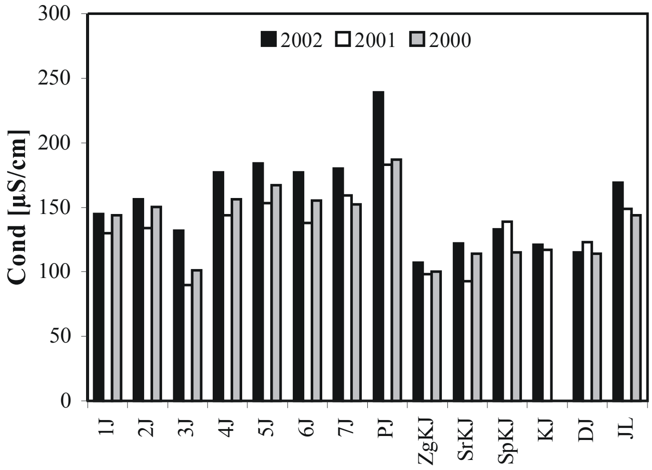


Figure 10. Conductivity (Cond) in the surface waters of the lakes in the three consecutive years (2000-2002) (see Table 1 for lake abbreviations).

Statistical analyses

Pearson correlation coefficients were calculated to obtain relations between the variables (Table 2). In addition, cluster analysis was performed to identify natural grouping in the variables (Figure 11). Nitrite and phosphate concentrations were below the level of detection and were therefore not included in these analyses. Temperature was also omitted, since it can vary substantially even during the day.[14] According to Table 2 and Figure 11, close relations were found between alkalinity and calcium, chloride and sodium, chloride and potassium, and chloride and calcium. In addition, most of the major ions were highly correlated to conductivity. However, alkalinity and calcium, the two principal parameters in the lakes, were the most strongly correlated to conductivity. These three parameters were also the closest clusters. Nitrate and sulfate were also closely related, suggesting that their origin might be the same. In most cases, atmospheric loading is the main source of these two anions in lake water.[15] Furthermore, geogenic variables (calcium, sodium, potassium, alkalinity) were well correlated with each other. Regarding nutrients, nitrate correlated well to TN, but the latter did not correlate significantly to TP. The pH was mostly negatively correlated to the majority of the variables. For instance, the pH and the alkalinity, as well as the pH and calcium, were negatively correlated, since an increase in pH is reflected in a decrease in the alkalinity and calcium, in accordance with a shift of the carbonate equilibrium that will be discussed later.

Table 2. Pearson correlation matrix for measured variables of all 14 lakes.

	Cl^-	NO_3^-	SO_4^{2-}	Alk	pH	Na^+	K^+	NH_4^+	Ca^{2+}	Mg^{2+}	tN	tP	Cond	O_2
Cl^-	1,00													
NO_3^-	0,22	1,00												
SO_4^{2-}	0,58	**0,73**	1,00											
Alk	**0,75**	0,36	0,67	1,00										
pH	0,00	-0,29	-0,25	-0,42	1,00									
Na^+	0,68	0,23	0,37	0,61	-0,35	1,00								
K^+	**0,72**	0,36	0,61	**0,71**	-0,10	0,24	1,00							
NH_4^+	0,57	0,01	-0,05	0,31	0,23	0,39	0,31	1,00						
Ca^{2+}	**0,70**	0,33	0,62	**<u>0,88</u>**	-0,57	**0,71**	0,67	0,30	1,00					
Mg^{2+}	0,21	0,27	0,32	0,25	0,44	-0,35	0,48	-0,01	-0,14	1,00				
tN	0,27	0,67	0,52	0,41	-0,21	0,58	0,21	-0,02	0,36	0,10	1,00			
tP	0,57	-0,40	-0,03	0,54	0,11	0,18	0,56	0,57	0,44	0,23	-0,24	1,00		
Cond	**0,75**	0,45	**0,73**	**<u>0,98</u>**	-0,43	0,63	**0,70**	0,27	**<u>0,88</u>**	0,24	0,51	0,45	1,00	
O_2	0,18	0,46	0,26	0,13	0,40	-0,12	0,18	0,28	-0,23	0,69	0,32	-0,06	0,12	1,00

Cluster analysis was also used to identify how the lakes group (Figure 12). Rjavo jezero and Jezero v Ledvicah are the closest clusters and are thus the most similar to each other of all 14 lakes. Together with Šesto jezero, Jezero pod Vršacem, and Spodnje Kriško jezero, they can all be grouped into one larger cluster. The lakes in this cluster are similar, since they belong to the upper Triglav lakes (except Srednje Kriško jezero). Most of them are also in good condition. The next cluster consists of the very similar Zgornje Kriško and Srednje Kriško jezero, and Zeleno and Krnsko jezero. However, the latter two differ from the former, since they are more productive. It is furthermore possible to group Peto and Črno jezero, together with Jezero v Lužnici, into the third cluster. The former two lakes in this cluster are more similar and also geographically closer. Nevertheless, all three lakes were occasionally found in a deteriorated condition, in particular Peto jezero. Dupeljsko jezero and Jezero na Planini pri Jezeru are entirely

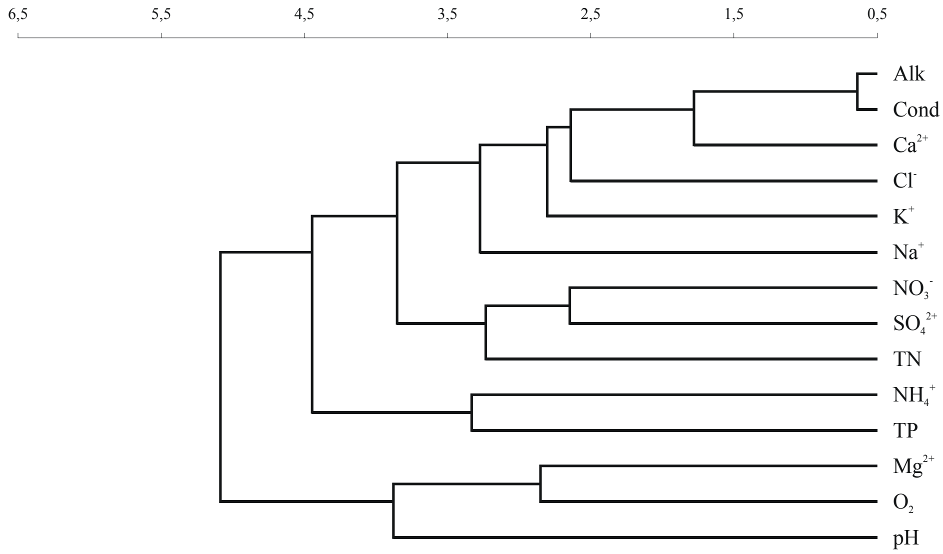


Figure 11. Cluster analysis dendrogram (standardized data, single linkage method, Euclidean distances) for measured variables.

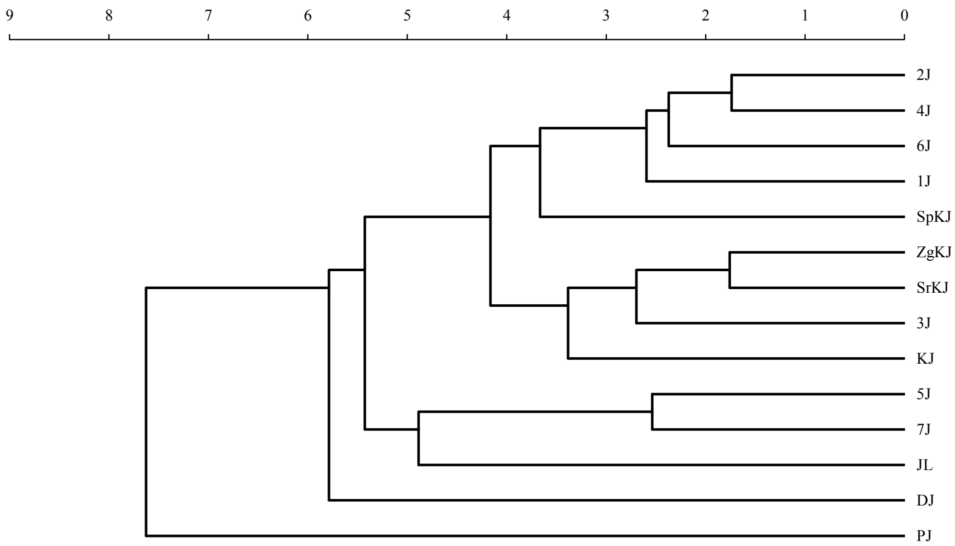


Figure 12. Cluster analysis dendrogram (standardized data, single linkage method, Euclidean distances) for all 14 lakes (see Table 1 for lake abbreviations).

different from all the other lakes. The former is a shallow, productive lake, with oxygen over-saturation in the water column, while the latter is a highly eutrophic, productive lake, with lack of oxygen in the water column.

Influence of lake and catchment area properties on water chemistry

Nitrate concentration in productive lakes, i.e. Jezero na Planini pri Jezeru, Krnsko, Zeleno and Dupeljsko jezero, was mostly below 0.2 mg/L. Low nitrate concentrations resulted from the high concentration of primary producers in these lakes, which caused an uptake of nitrates by aquatic organisms.[15] Although nitrate concentration was also low in the Kriško lakes, these low concentrations were more probably related to the small catchment areas with weak or no vegetation, resulting in a lower surface run-off.

The lowest sulfate concentrations were also observed in the lakes with the smallest catchment areas.

The alkalinity was low in the Kriško lakes. Their catchment areas are small, but in carbonate watersheds weathering is the main source of carbonate (related to the alkalinity) and calcium in the water column.[16] Low alkalinity values were also observed in several productive lakes, i.e. Zeleno and Dupeljsko jezero. These two shallow lakes are overgrown by vegetation over the entire lake bottoms. Primary production is hence rich, resulting in a drop of carbon dioxide concentration and an increase of dissolved oxygen concentration in the surface water layers. The pH values were consequently high, while the alkalinity was lower due to shift in the carbonate equilibrium.[9] A similar, but less intensive process was also observed in Krnsko jezero. In contrast, the highest alkalinity was observed in Jezero na Planini pri Jezeru. Since this lake is also productive, the alkalinity should rather follow the distribution, as observed in other productive lakes. Nevertheless, transparency of the water column in Jezero na Planini pri Jezeru is low, resulting in low photosynthesis. We suppose that respiration predominates over photosynthesis also in the upper water layers, and consequently carbon dioxide concentration is high. The pH dropped, while the alkalinity increased, according to a shift of the carbonate equilibrium.

Calcium concentration was low in the Kriško lakes, since their catchment areas are small. Weathering of bedrock, the main origin of major cations in lakes,[9,17] was consequently low. Low calcium concentrations in the productive Krnsko, Dupeljsko and Zeleno jezero were related to a shift of the carbonate equilibrium. Since the pH was high in these lakes, calcium carbonate precipitated in the surface water layers, and consequently lower calcium concentrations were observed in these waters. The highest calcium concentration, observed in Jezero na Planini pri Jezeru, was however related to the opposite process in the carbonate equilibrium. Due to a lower pH value, carbonate concentration decreased, and consequently calcium carbonate dissolved to reach equilibrium again. Thus, calcium concentration in the surface water was higher.

Low magnesium concentration was observed in the Kriško lakes. All these lakes have small catchment areas. The highest concentrations were observed in the Krn lakes and could be related to the difference in the bedrock geology of this area. Compared to the other lakes, a higher content of dolomites was found in the catchment areas of the Krn lakes,[6,7] probably resulting in higher magnesium concentration.

Chloride, sodium and potassium concentrations were fairly uniform in all the lakes and were therefore not substantially affected by the specific lake and catchment area properties.

The TN/TP ratio was calculated to assess whether nitrogen or phosphorus is the growth-limiting nutrient in the lakes. The TN/TP ratios were high, ranging from 42 to 242. Nitrogen limitation may be common in lakes with the TN/TP ratios less than 14,[18] while the ratios tend to be greater than 17 in phosphorus-limited lakes.[19] From these high TN/TP ratios it can be concluded that the Slovenian mountain lakes are primarily phosphorus limited.

Dissolved oxygen is one of the fundamental parameters of lakes, since it is essential to the metabolism of all aerobic aquatic organisms.[10] The lowest oxygen concentration/saturation was observed in eutrophic Jezero na Planini pri Jezeru, dropping to 90% on some occasions. This drop is most probably related to consumption of oxygen through organic matter degradation in the water column.[4] Oxygen conditions in the lakes also affected the oxidation state of several chemical parameters. Surface waters of all the lakes were generally well saturated with oxygen. Thus, completely oxidized forms of ions (nitrate and sulfate) predominated. Nevertheless, reduced forms (ammonium and also nitrite) were occasionally observed, but only in the deeper water layers of highly productive lakes, such as Jezero na Planini pri Jezeru, due to lack of oxygen caused by degradation of organic matter.[8]

Condition of the lakes

Most Slovenian mountain lakes are still in a good condition. The lakes are mostly oligotrophic to oligotrophic/mesotrophic, since their concentrations of nutrients (TP) and chlorophyll[4] are low, while transparency in the water column is high. Thus, primary production in these lakes is, combined with low water temperature, moderate. In contrast, intensive primary production was observed in several lakes, i.e. Zeleno, Dupeljsko, Krnsko jezero and Jezero na Planini pri Jezeru. These lakes are mesotrophic to eutrophic, while Jezero na Planini pri Jezeru can be classified as eutrophic/hypereutrophic. Zeleno and Dupeljsko jezero are in a somewhat better condition than Krnsko jezero and Jezero na Planini pri Jezeru. The former lakes are shallow, with vegetation growing over the entire lake bottoms. They are thus over-saturated with oxygen and have a rather good water quality. In contrast, the latter lakes, in particular Jezero na Planini pri Jezeru, have high nutrient and low dissolved oxygen concentrations and low transparency. As a consequence, the water quality has deteriorated markedly.

Conclusions

Major ions, total nitrogen and total phosphorus, as well as temperature, conductivity and oxygen concentration/saturation were determined once a year in the surface waters in 14 Slovenian mountain lakes over the three consecutive years (2000-2002). The data were also analyzed statistically to identify relations between variables and natural grouping in the data.

It was found that biological conditions in the water column are important. The pH, alkalinity, calcium concentration and conductivity were evidently dependent on the rate of primary production in the lakes, due to subsequent shifts in the carbonate equilibrium. The highest correlation was found between the latter three parameters. Furthermore, the size of the catchment area also affected water chemistry. The lakes with smaller catchment areas had lower total concentrations of dissolved ions, due to smaller surface run-off. In addition, cluster analysis showed that the upper Triglav and the upper Kriško lakes were the most similar lakes. Thus, the more similar lakes were found to be located geographically close together. In contrast, Jezero na Planini pri Jezeru and Dupeljsko jezero were entirely different from any other lake.

Most of the lakes are still oligotrophic/mesotrophic and therefore in a good condition. Nevertheless, the water chemistry in some lakes (such as Jezero na Planini pri Jezeru and also Krnsko jezero) has deteriorated. The former, in particular, is highly eutrophic, with lack of oxygen in the water column.

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Povzetek

Analizirali smo osnovne fizikalne in kemijske lastnosti vode v 14 slovenskih visokogorskih jezerih. Od leta 2000 do 2002 smo enkrat letno pobirali vzorce površinske vode. Študirali smo vpliv lastnosti jezera in pojezerja na merjene parameter. Izkazalo se je, da trofično stanje jezera in velikost pojezerja občutno vplivata na kemijske parametre. Podatke smo tudi statistično obdelali. S Pearsonovimi korelacijskimi koeficienti smo določili medsebojno povezanost med parametri. Največjo korelacijo smo ugotovili med alkaliteto, kalcijem in prevodnostjo. Napravili smo tudi klastersko analizo, da smo podobna jezera lahko uvrstili v skupine. Na koncu smo ocenili še stanje jezer. V večini jezer je kvaliteta vode še vedno dobra, v nekaterih jezerih (predvsem Jezero na Planini pri Jezeru) pa se je poslabšala.