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PHYSICOCHEMICAL CHARACTERISTICS OF DAM LAKES IN SOUTHWESTERN BULGARIA

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Abstract

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The validity of the defined water body types in Bulgaria and the relationships between the nutrient concentration and the response variables to eutrophication was tested in eight reservoirs in the Struma River Basin. The applicability of different classification schemes based on reservoirs' morphological and physicochemical characteristics are presented and discussed. The similar response of the lakes to changes in TP has proved the relationships underlining the classification of lakes relative to eutrophication, and suggests possible restriction, or at least a redistribution of the reservoirs among the lake types. All tested variables responded markedly to eutrophication, and only the aquatic plants showed limitation both at low as well as at high nutrient levels.

The theoretical residence time and the fluctuation of the water table influence the nutrient levels and thus the response variables to the eutrophication in the reservoirs. This emphasizes the problem of how a rather limited sampling program, based on one or a few annual samplings, can provide an adequate and correct definition of the ecological state in the future.

Further studies, concerning the validity of the typology system in Bulgaria are needed before the establishment of type specific reference conditions and a consequent calculation of the EQR values for the individual biological quality elements.

Key words: WFD, BQE's, total phosphorus, chlorophyll-a, macrophytes, reservoirs

Introduction

In the period 2001-2006, in accordance with the administrative and legislation transformations major changes have taken place in Bulgaria concerning the policy of water resources use and conservation, due to the preparation for accession to the European Union and the adaptation of the Water Framework Directive (2000/60/EC) (WFD). This strategic document was adopted to protect and improve the quality of all surface water resources. The main priority of WFD is the establishment of common criteria for typology sys-

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tem and classification of the water basins, monitoring and assessment of the ecological state of waters.

According to the Directive, the assessment of the impact on water bodies should not be based on environmental standards but on ecological ones, which are strongly influenced by the type of water bodies and the characteristics of the ecoregions.

The diversity of physicogeographic conditions in Bulgaria determines the immense diversity of limnetic waters. There are more than 500 natural lakes and more than 2500 different purpose reservoirs (Michev and Stoyneva (edt.), 2007). The surface waters in Bulgaria are grouped in types according to the main criteria of "System B" typology, listed in Annex II of the WFD. This system includes parameters such as coordinates, altitude, morphometry and basin chemistry.

The concept of biological monitoring in the Bulgarian lakes and reservoirs has never been applied prior to the introduction of the typology system in Bulgaria (2006), and the implementation of the first monitoring programs in compliance with the requirements of the WFD (from November 2007). This determines the lack of systematic information on the existing conditions influencing the development of the different biological quality elements (BQEs) as well as on the trophic state of water bodies. This impedes the assessment of relationships between the imposed typology, the trophic state of water bodies and the corresponding distribution of the BQEs, which is needed for the assessment of their ecological state.

So far, the bulk of scientific papers in Bulgaria has been focused on the influence of certain pollutants on different trophic levels in the food chain, or on different components of the lake communities. Considerably less have been the investigations on the changes in the trophic state and the corresponding shifts of the plankton and benthic communities in the limnetic waters, aiming at the qualitative and quantitative description of the relationships. Investigations on the factors, influencing the development of spatial gradients of the main physicochemical parameters in lakes and reservoirs in Bulgaria, and the corresponding responses of the communities have been done by the following authors: Naidenow (1970); Naidenov (1984); Naidenov and Baev (1987); Kalchev (1999); Kalchev et al. (1996); Kozuharov (1994; 1996; 1999); Traykov (2005); Kozuharov et al. (2007; 2009).

Investigations on the factors, influencing the Chlorophill-a (Chl-a) content in the biomass of the phytoplankton and the effects of zooplankton on phytoplankton abundance and composition: Kalchev, (1994); Kalchev and Boumbarova (1996); Kalchev et al. (1996; 2003; 2004) and Traykov (2005).

The main investigations on the composition of aquatic macrophytes in Bulgaria are the ground works of Yordanoff (1931), Kochev and Jordanoff (1981) and Kochev (1983) among others. The only preliminary investigation on the applicability of macrophytes to be used as indicators for the assessment of water quality is presented in Uzunov (ed) (2005).

In order to evaluate the trophic state as well as the proposed classification of the dam lakes, we selected total phosphorus (TP) as key variable for lake water quality assessment. Clearly, the classification of lakes must be based on biological quality elements (BQEs), but the initial step is to determine the trophic state of water bodies according to the nutrient concentration with subsequent description of the distribution of the BQEs – chlorophyll-a and aquatic macrophytes along the trophic gradient in the lakes.

Our aims were to: (i) provide data and test the validity of the defined water bodies in type "lake" in the Struma River Basin, according to their physicochemical characteristics, and (ii) determine the relationship between the nutrients concentration and chlorophyll-a.

Materials and Methods

A total of eight reservoirs were investigated on 25 – 30 June 2009 on the territory of the Western Aegean River Basin Directorate (Figure 1).

The sampling was done on one site in the deepest part of the reservoirs. Integrated samples from the epilimnion were collected for physicochemical analyses using standard methods and equipment (Wetzel and Likens, 2000).

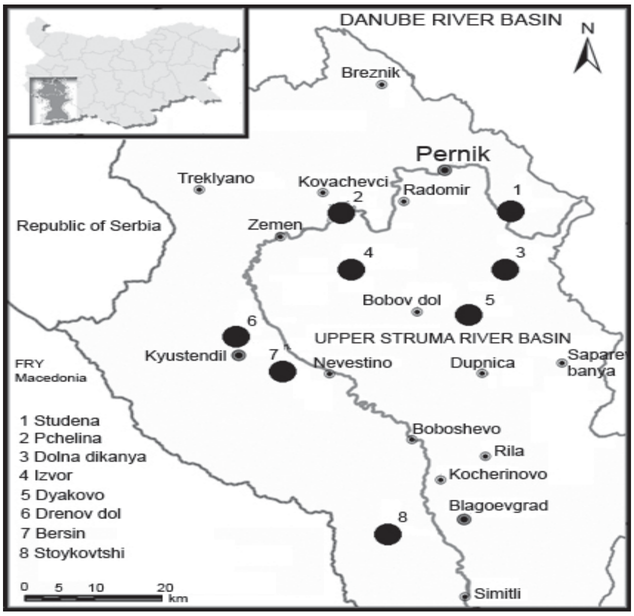

Fig. 1. Relative position of the studied reservoirs within the upper Struma River Basin

Although the River Basin Authority includes high altitude natural and man-made lakes in their classification, we have focused our investigation on dam lakes below 900 m a.s.l and surface area > 0.5 km^2. Two of the reservoirs (Studena and Pchelina) are situated on the main river, while the rest are on side tributaries.The investigated reservoirs differ morphologically, but relatively deep lakes prevail (Table 1).

On site measurements of water transparency (Secchi disc visability), dissolved oxygen (WTW 3310), electrical conductivity and pH (HI 98129) were conducted.

Chemical analysis of water samples included TP and total nitrogen concentrations (colorimetrically after CracTest digestion in autoclave, MERCK – PMB methods 14848 and 14773, corespondingly), chlorophyll-a (acid corrected, ISO 10260) and total alkalinity (ISO 9963-1. 2000). Non-algal turbidity (NAT, m^{-1}) was calculated as: 1/Secchi – 0.025[Chlorophyll-a] (WALKER, 1985).

For all of the lakes we used the following values of TP defining the five categories as a guide for the state of the reservoirs (Table 2). The choice of the boundary values is based on the previous works of Uzunov (2005).

Chemical and biological data were also available for most reservoirs from previous investigations (Beshkova (1996); Beshkova and Botev (1994); Kozuharov (1994; 1996; 1999); Traykov and Boyanovsky (2003); Kozuharov et al. (2007; 2009)). These data were included in the calculation of the mean and standard deviation of the parameters. The high mean depth of the lakes (>5m) ensures that they are permanently stratified during the summer (Sondergaard et al., 2005).

Descriptive statistics were conducted for the studied environmental variables. The relationships between the variables were assessed by means of Spearman rank correlation. All analyses were performed using Statistica 6.0 software.

Table 1

Attributes of the reservoirs, included in the study

Reservoir	Elevation, m a.s.l.	Surface aria, km^2	Max.depth , m^{-1}	Volume, $m^3 \times 10^6$	Average depth, m^{-1}
Dyakovo	670	2.0	53	35.40	17.7
Stoykovtshi	600	1.1	30	13.50	11.9
Dolna Dikanya	705	0.9	17	7.22	8.0
Izvor	490	0.8	26	7.3	9.1
Drenov Dol	540	0.64	20	3.5	5.5
Bersin	500	0.54	30	4.6	8.5
Pchelina	620	5.4	22	54.80	10.1
Studena	840	2.5	50	25.20	10.1

Table 2
Suggested total phosphorus class boundaries between the five categories

Mean epilimnetic TP concentration, µg.l^{-1}					
	High	Good	Moderate	Poor	Bad
TP Range	TP < 25	25< TP <50	50< TP <70	70< TP <100	TP >100

Results and Discussion

We present data on selected physical and chemical variables in reservoirs from the three mid-altitude reservoir types along the Struma River valley. The distribution of the water bodies among the three types is not equal with four reservoirs in type 27, three in 26 and only one in reservoir type 29 (Table 3). The results show high variability even among the reservoirs from the same type.

The reason for this heterogeneity in the results is the proposed typology itself. The classification in Bulgaria is based on Type B classification scheme for natural lakes (WFD, 2000). In reality, more than 90% of the lentic water bodies, included in the monitoring, are reservoirs, which are highly modified water bodies instead.

The mean values of the variables do not show marked changes among the water body types (Figure 2). Only the differences in total alkalinity and electrical conductivity are more prominent for type 29 (Studena reservoir). The rest of the variables show considerable range within the defined water body types, and in most cases there is an overlap between the 25th and 75th percentile for adjacent types.

Generally, the differences between the individual lakes in the Struma River watershed are not so strong, with the only exception being Pchelina reservoir. The later shows similar distinguishing features in the work of Kozuharov et al. (2009). The higher trophic state of the reservoir reflects its use as a stilling basin for the heavily loaded river waters below the industrial zones of Pernik and Radomir towns.

The inclusion of Pchelina reservoir in type 26 res-

Table 3
Reservoir type and corresponding physicochemical parameters. Data: River Basin Directorate

Type	Studena	Pchelina	Stoykovtshi	Dyakovo	Dolna Dikanya	Izvor	Drenov Dol	Bersin
	29	26			27			
SD m^{-1}	29	2.05	5.3	4.3	2.2	2.6	5	2.5
pH	2.52	7.5	8.21	7.8	7.9	8	8.2	8.22
EC uS.cm^{-1}	169	495	305	120	233	318	166	356
DO mg.l^{-1}	9.6	5.9	7.8	7.9	7.9	7.4	8.3	8.2
TA meq.l^{-1}	1.22	4.26	2.43	1	2.18	3.26	1.25	2.4
TP mg.l^{-1}	0.064	0.39	0.02	0.01	0.012	0.02	0.03	0.01
TN mg.l^{-1}	0.69	1.5	0.22	0.1	0.1	0.1	1.7	1.3
Chl-a µg.l^{-1}	8.26	18	1.33	1.1	2.13	1.9	0.9	2.7
NATm^{-1}	0.28	0.04	0.16	0.21	0.38	0.34	0.18	0.33
No. of AP*	2	3	8	2	2	2	3	3

* No. of AP – Numbers of observed aquatic plants – excluding helophyte vegetation on the shoreline

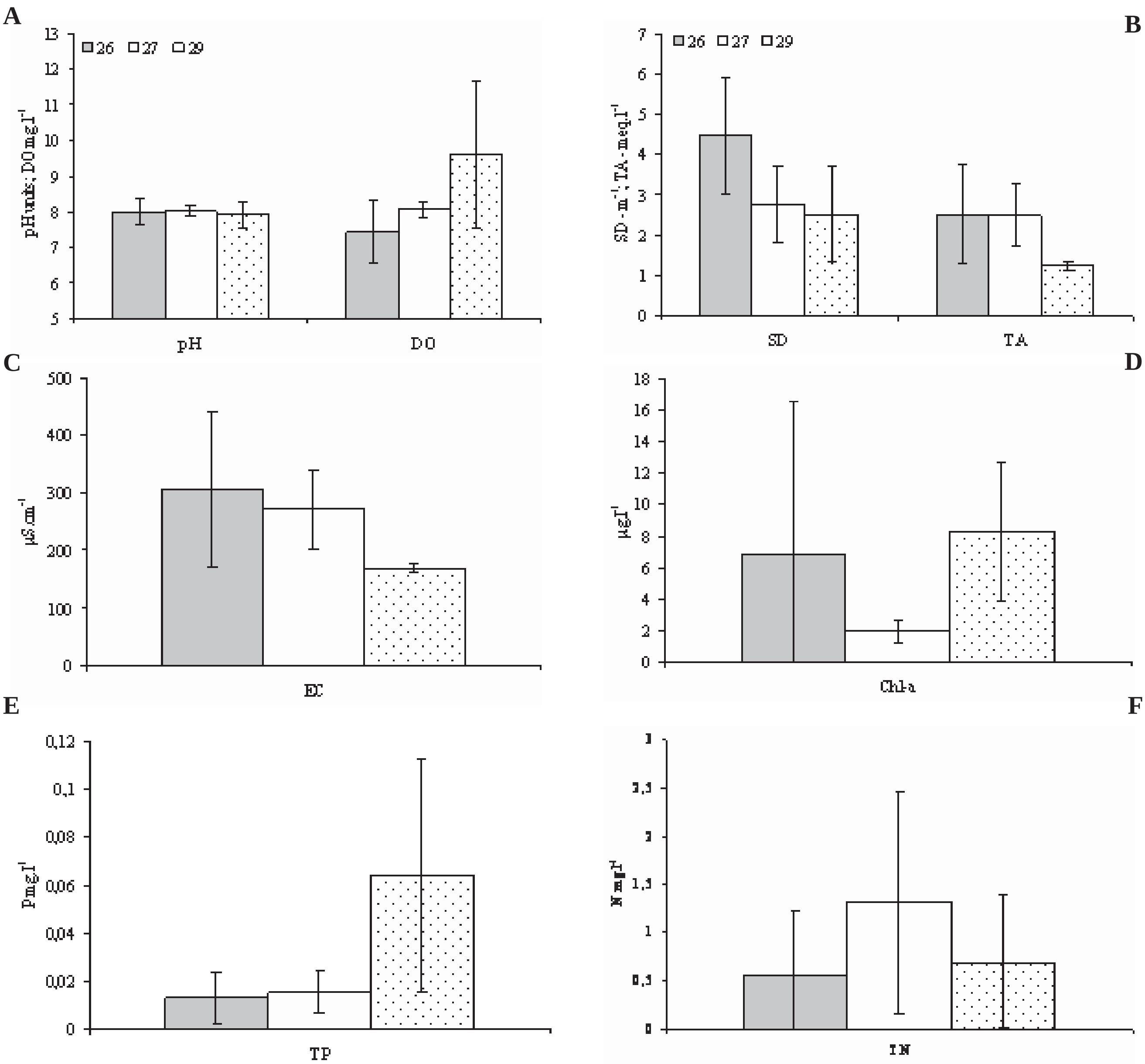

Fig. 2. Mean values of: pH and DO – a); transparency and total alkalinity – b); electrical conductivity – c); Chlorophyll-a – d); total phosphorus – e) and total nitrogen – f) in the three lake types. Vertical bar shows the standard deviation of the variables

ervoirs skews the data sets and alters the overall comparison with the rest of the reservoirs. In our opinion, the reservoir should be excluded from the general typology and special site specific requirements assigned prior to defining its ecological state.

As an alternative to type B differentiation of the reservoirs, we presented the data along a TP gradient, and their variability within each of the pre-selected TP classes. The reservoirs grouped differently, compared to Type B classification scheme for natural lakes. The three reservoirs Dolna Dikanya, Bersin and Dyakovo grouped under high ecological quality, another three - Drenov Dol, Izvor and Stoykovci- under good ecological quality. Studena and Pchelina

Table 4
Average values of the physicochemical variables for each ecological quality class

	High	Good	Moderate	Poor	Bad
TP $\mu g.l^{-1}$	9	23	64	n.a.	390
SD m^{-1}	3.00	4	2.52	n.a.	2.05
pH	8.0	4.30	7.7	n.a.	7.5
EC $\mu S.cm^{-1}$	236	263	169	n.a.	495
DO $mg.l^{-1}$	8.0	7.8	9.6	n.a.	5.9
TA $meq.l^{-1}$	1.86	2.31	1.22	n.a.	4.26
TN $mg.l^{-1}$	0.5	1.4	0.7	n.a.	1.5
Chl-a $\mu g.l^{-1}$	1.98	1.38	8.26	n.a.	18.00
NATm^{-1}	0.29	0.22	0.24	n.a.	0.04
No. of AP	3	9	2	n.a.	3

reservoirs showed moderate and bad ecological quality, respectively. The average values of the studied variables for each ecological quality class are presented in Table 4.

As we used only the values of TP to distinguish between the five categories, the values in the Moderate class do not fit the expected overall trend along the TP gradient. The reason for this is that data from only one reservoir fall into this category in the Struma River basin. Obviously, the high TP value in Studena reservoir is the reason for the observed discrepancies. The relatively short theoretical residence time of the reservoir (approximately 60 days) and the strong fluctuations of the water level (on average 9 m) are responsible for the increased TP values.

To evaluate the relationship between TP as a class variable and the rest of the studied variables, we conducted correlation analyses. Regardless of the observed discontinuities in the Moderate class, the correlation between mean values of TP and the rest of the variables at each ecological quality class is very strong (Table 5).

Secchi depth transparency, DO, pH and non-algal turbidity, were all negatively related to TP, while EC, total alkalinity, total nitrogen and the amount of chlorophyll-a showed opposite trends. The positive relationship of TP with EC and TA reflects the natural influence of the edaphic factor in the watershed. The opposite relation with the amount of the phytoplankton (expressed as Chl-a) and non-algal turbidity indicates decreased influence of color and suspended sediments on the Secchi disk depth readings at higher trophic state.

All of the selected variables responded markedly to the changes in TP, thus proving the relationships underlining the classification of lakes relative to eutrophication.

The number of the aquatic plants, included in the analyses, decreased with increasing TP. As this variable is strongly influenced by water level fluctuations as well as by the fish population of the reservoirs, we cannot conclude about its distribution along the TP gradient. Based on the preliminary observations on the reservoirs in the Struma River basin, it seems that the aquatic plants are limited both at low as well as at high nutrient levels. Due to the relatively small data set, we cannot discuss the species preferences to the trophic state of the reservoirs.

Overall, however, in the different lakes used in this study, most indicators had a relatively similar response to eutrophication, which suggests that the number of the lake types can be restricted or at least a redistribution of the reservoirs among the lake types should be considered. Furthermore, the current classification

Table 5
Correlation matrix between TP means values and the respective values of physicochemical variables at each ecological quality class

	SD	pH	EC	DO	TA	TN	Chl-a	NAT	No. of AP
TP	-0.677	-0.831	0.921	-0.779	0.897	0.596	0.957	-0.974	-0.307

system does not take into account parameters such as theoretical residence time and water level fluctuation, which are one of the most important drivers, shaping the response of the reservoirs to the eutrophication stressors.

It could be argued, that the use of a single fixed boundary TP gradient, defining the five categories is irrelevant, as for the WFD's classification type specific scale should be used. Our analyses, however, aim at testing the validity of the typology system, not defining the ecological quality of the individual reservoirs.

Another significant problem is whether the classification of the lakes and reservoirs should be based on measurements from a single year or whether sampling and data analyses should try to compensate for natural inter-annual variability. We used the available data from the last 15 years and produced summer averages of between one and 43 samples per reservoir, which yielded high variability. This emphasizes the problem of how a rather limited sampling program, based on one or a few annual samplings, can provide an adequate and correct definition of the ecological state in the future.

Conclusion

Further studies, concerning the validity of the typology system in Bulgaria are needed before the establishment of type specific reference conditions and a consequent calculation of the EQR values for the individual biological quality elements. The situation is further complicated as the majority of water bodies in the lake type are actually reservoirs, for which instead of reference conditions, maximal ecological potential should be defined.

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