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PRINCIPAL COMPONENT ANALYSIS OF THE PHYTOPLANKTON INTERACTIONS WITH THE ENVIRONMENTAL FACTORS IN TWO RESERVOIRS IN BULGARIA

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Abstract

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In the present study, we have analyzed the connection between the main environmental parameters and the quantitative characteristics of the phytoplankton communities in two economically significant Bulgarian reservoirs (Kardzhali and Dospat) for a one-year period (April 2011 – April 2012). The aim of this study was to identify the key environmental factors influencing the phytoplankton development, by implementation PCA analysis based on the Pearson correlation matrix. The conducted PCA identified 5 principal components, which explained 83.64% and 79.91% of the total variance for both reservoirs respectively. The data analysis indicates, that physical parameters, such as water transparency (Sd), electrical conductivity (Cond.), pH, concentration and saturation of the dissolved oxygen (O_2, O_2%), and the different forms of nitrogen and phosphorus (NO_3-N, TN, PO_4-P, TP, COD_{Mn}), as well as a total count of heterotrophic bacteria (TVC) have considerable impact on the phytoplankton dynamics in Kardzhali reservoir. Similar dependences between environmental factors and phytoplankton community, with the exception of O_2 and O_2%, were established for Dospat reservoir. The obtained results demonstrate the applicability of the multivariate statistical analysis methods for the determination of the main factor influencing the quantitative, spatial and seasonal phytoplankton development in heavily modified water bodies.

Key words: principal component analysis; phytoplankton; reservoirs; environmental factors; TVC
Abbreviations: TVC – total count of heterotrophic bacteria

Introduction

At present the surface freshwaters worldwide, such as rivers, reservoirs and lakes are undergoing an extensive qualitative and quantitative, physical, chemical and biological alterations as a result of hydrological and biogeochemical changes (Carpenter et al., 2011). Their exploitation characteristics often lead to large water level fluctuations, which leads to eutrophication and ecological pressure on the biological communities (Carol et al., 2006). In this regard phytoplankton is an important indicator of trophic status changes in the environment. The structure of the community is a result of the integrated effect caused by the elevated nutrient loading. As a result, they may be more sensitive to the combined effects of the stress factors than to a single stress source (Cabecinha et al., 2009). Knowledge of the mechanisms that underlie the phytoplankton models can be useful in the development of water qual-

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ity criteria and management planning. It is important to analyze the interactions between environmental parameter changes and the phytoplankton dynamics in order to gain a better understanding of the factors, responsible for the annual phytoplankton community fluctuations (Arhonditsis et al., 2004). There are substantial difficulties in the use and interpretation of large data sets resulting from monitoring programs, especially if the number of study parameters is large. Factor analysis is particularly useful for the description of the relationship of a number of observed random environmental variables (Wang et al., 2007). It is implemented for the identification of the seasonal changes of the environmental factors and the phytoplankton groups (Wu et al., 2014). The statistical methods are useful for the interpretation of complex data matrices and the comprehension of the ecological state and water quality in the studied water bodies. This makes it possible to identify the potential impact sources which make such analyses a valuable tool in the water resources management. Implementation of statistical methods for characterization and evaluation of the surface freshwater quality has proven to be a useful tool in the investigation of temporal and spatial changes caused by environmental and anthropogenic factors related to season changes (Wunderlin et al., 2001; Simeonova et al., 2003; Simeonov et al., 2003; Shrestha and Kazama, 2007). There are several studies in Kardzhali and Dospat reservoirs focused mainly on the effects of fish cage farming in Bulgaria on physical and chemical water parameter and algal flora in the last decade (Traykov, 2005; Belkinova et al., 2007; Iliev and Hadjinikolova, 2011; Hadjinikolova and Iliev, 2012; Dochin, 2014; Dochin and Stoyneva, 2014; Dochin and Stoyneva, 2016; Dochin et al., 2015). The aim of the present study was to implement principal component analysis in order to reduce the number of variables by combining the correlating factors in new principal components and to identify the variables with the strongest impact on the phytoplankton growth in Kardzhali and Dospat reservoirs.

Materials and Methods

Study sites and water sample collection

The study was conducted in the Kardzhali and Dospat reservoirs, located in the Rhodope Mountains; Bulgaria. Both reservoirs are used for intensive cage fish farming for more than 30 years. The cultured species in Kardzhali reservoir include sturgeons (Acipenseridae), common carp (*Cyprinus carpio*) and wels (*Silurus glanis*) while in Dospat reservoir is reared only rainbow trout (*Oncorhynchus mykiss*). The main morphometric characteristics of the reservoirs are presented on Table S1. The water samples were collected for the period April 2011 – April 2012 using standard methods and according the Bulgarian and European regulations (EU Water Framework Directive 2000/60/EC). Sampling was conducted at six sampling sites in each of the reservoirs (Figure 1).

Table S1
Morphometric characteristics during the investigation period of the reservoirs Kardzhali and Dospat

	Reservoir Kardzhali	Reservoir Dospat
Geographic coordinates	41°37′25°20′	41°41′24° 05′
Average heigh (m.a.s.l.)	280	1280
Volume (m^{-3})	497 235 698	449 248 693
Aquatory (m^{-2})	15 991 735	22 099 371
Maximum length (m)	22 000	19 000
Average width (m)	1323	683
Average depth (m)	31	20
Maximum depth (m)	74.3	50
Watershed basin (km^{-2})	1882	432.3
Retention time (days)	205	180
Tributary	Arda river	Dospat River

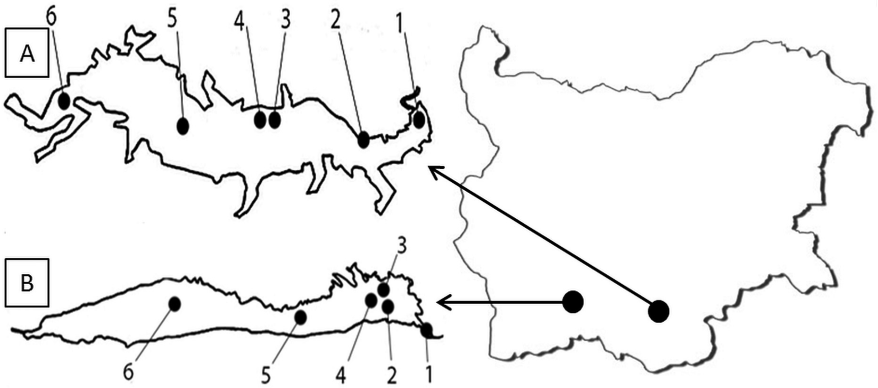

Fig. 1. Maps of the reservoirs: A: Kardzhali and B: Dospat with their position in Bulgaria and location of the studied sites

Physicochemical analysis

Water temperature (T,°C), dissolved oxygen (O_2, mg.L^{-1}) and oxygen saturation (O_2%) were measured in situ with oxygen meter (WTW OXY 1970i). Water transparency (Sd) was determined by the Secchi disk method. Electrical conductivity (Cond., µs/m) and pH were measured with WTW conductivity meter (Cond3310/SET) and WTW pH-meter (315/SET) respectively. Ammonium (NH_4-N), nitrate (NO_3-N) and total nitrogen (TN, mg.L^{-1}), orthophosphates (PO_4-P, mg.L^{-1}). Manganese III COD (COD_{Mn} mg.L^{-1}) were measured in laboratory using standard analytical methods (ISO 8467:1993; ISO 5664:1984; ISO 7890-1:1986; ISO 6878:2004). Total phosphorus (TP mg.L^{-1}) concentration was measured by Phosphate Cell Test (114543, Merck Millipore).

Analysis of biological factors

The water samples for analysis of phytoplankton were collected by Niskin-Type water sampler (Hydro-Bios Apparatebau GmbH, Germany) and processed by standard method of fixation with formalin to final concentration 4% and further sedimentation. Detailed information concerning the species composition and seasonal dynamics of the phytoplankton in both reservoirs for the period 2009-2012 are presented in our previous publications (Dochin, 2014; Dochin and Stoyneva, 2014; Dochin, 2015; Dochin and Stoyneva, 2016). The numbers (Ph_N) is expressed as (x10^{-6} cells.L^{-1}). The biomass (Ph_B) is expressed as (mg.L^{-1}). The water samples for determination of the total count of viable bacteria (TVC) were collected from the superficial layer (0.5 m below the surface), metalimnion and bottom layer (1 m above the sediment) using MICROS water sampler (Hydro-Bios Apparatebau GmbH, Germany). TVC, determined at 22°C, was expressed as colony forming units per liter (cfu.L^{-1}).

Statistical analysis

PCA analysis was conducted to retrieve the key trends between the variables of the environment and the phytoplankton data. PCA analysis was used for the determination of the key trends between the changes in the environmental parameters and the phytoplankton dynamics. A Pearson correlation matrix, reflecting the interconnection correlation between all tested indicators and the level of significance of the respective correlations, was generated in order to set the number of principal components. Statistical data analysis was performed with SPSS v. 13 (IBM Analytics).

Results

Factor analysis was used for reduction of dimensionality of the original n-dimensional space by establishing a new basis of factors. In the present study the initial set of 15 parameters was reduced by grouping the correlating factors in common main components and the separation of the non-correlating parameters, thus defined smaller number of summarized factors, which separately doesn't have meaning, but they integrate the features of several indicators. The adequacy evaluation was performed by Kaiser-Meyer-Olkin and Bartlett tests. The results indicated that the obtained data were suitable for performing factor analysis and that the suggested model is adequate. By performing a PCA analysis, it was found that five factors had values of eigenvectors greater than 1, which determined the choice of five principal components (Figure 2 and 3). A correlation matrix was used as a basis for the application of the PCA analysis (Table S2). We used Pearson`s linear correlation coefficients for the determination of the environmental variables with highest impact on the phytoplankton community. The study of the 15 main

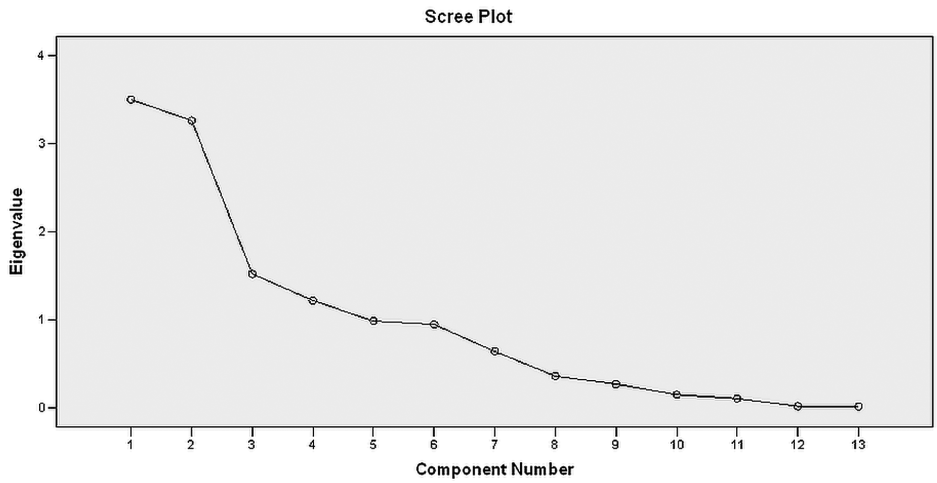

Fig. 2. Values of their own vectors in Kardzhali reservoirs 2011-2012

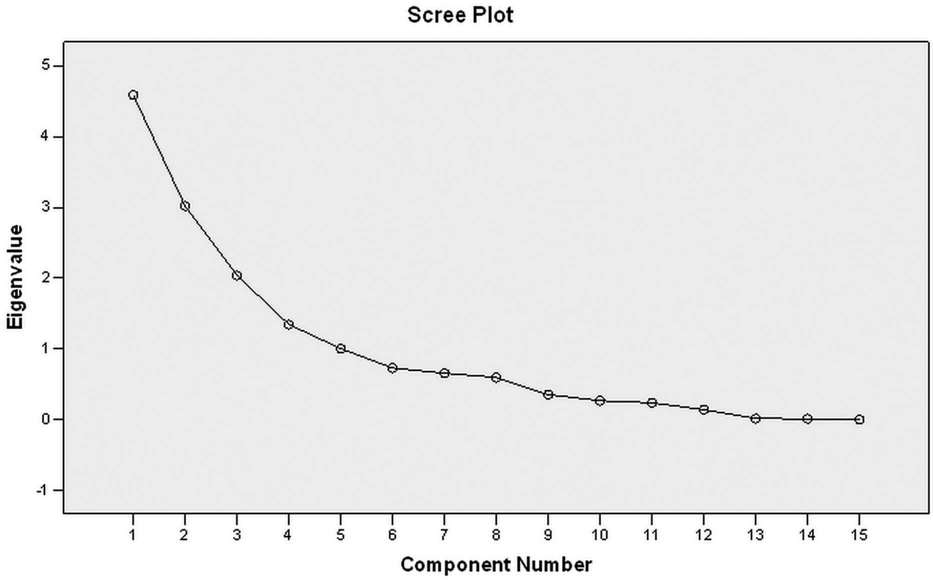

Fig. 3. Values of their own vectors in Dospat reservoirs 2011-2012

variables presented in the correlation matrix showed good consistency of results. During the study period 2011-2012 a significant positive correlation dependency was determined for most of the analyzed physical and chemical parameters in the aquatory of Kardzhali reservoir (Table S2). According to the correlation coefficients, indices with the strongest impact on the phytoplankton development in Kardzhali reservoir include O_2, O_2%, pH, TP, Sd and Cond. Positive correlation was established for all of the parameters with the exception Sd and Cond. (Table S2).

The results from the PCA analysis for Kardzhali reservoir showed that the first principal component (PC1) depleted 29.13% of the total variance with values of 24.44%, 12.99%, 8.87% and 7.20% respectively for the second (PC2), third (PC3), fourth (PC4) and fifth (PC5) component. It is visible from the results that the five main parameters covered

Table S2
Pearson correlation matrix of the physico-chemical parameters and phytoplankton in Kardzhali Reservoir 2011-2012

	Ph_N	Ph_B	Sd	T°C	Cond.	pH	O_2	O_2%	NH_4-N	NO_3-N	TN	PO_4-P	TP	COD_{Mn}	TVC
Ph_N	1														
Ph_B	0.961**	1													
Sd	-0.231*	-0.196*	1												
T°C	-0.078	-0.099	0.487**	1											
Cond.	-0.197*	-0.154	0.783**	0.165	1										
pH	0.222*	0.192*	-0.235*	0.405**	-0.377**	1									
O_2	0.331**	0.314**	-0.645**	-0.397**	-0.467**	0.146	1								
O_2%	0.290**	0.290**	-0.477**	0.003	-0.422**	0.417**	0.902**	1							
NH_4-N	-0.116	-0.067	0.488**	-0.047	0.767**	-0.329**	-0.117	-0.133	1						
NO_3-N	-0.105	-0.062	-0.361**	-0.856**	-0.155	-0.415**	0.290**	-0.05	0.085	1					
TN	-0.102	-0.071	-0.344**	-0.858**	-0.114	-0.448**	0.269**	-0.075	0.147	0.966**	1				
PO_4-P	-0.016	0.019	-0.079	-0.632**	0.256**	-0.277**	0.274**	0.037	0.516**	0.613**	0.628**	1			
TP	-0.207*	-0.194*	0.088	0.004	0.176	-0.013	-0.283**	-0.275**	0.06	0.124	0.114	0.176	1		
COD_{Mn}	-0.182	-0.155	-0.028	0.363**	0.043	0.168	-0.204*	-0.022	0.019	-0.321**	-0.302**	-0.324**	0.151	1	
TVC	-0.119	-0.139	0.246*	0.480**	-0.037	0.092	-0.360**	-0.189	-0.184	-0.380**	-0.398**	-0.381**	0.045	0.102	1

*Correlation in significant at the 0.05 level (2-tailed)
**Correlation in significant at the 0.01 level (2-tailed)

82.63% of the total variance and confirmed the graphic interpretation of the results, that the first five factors are the main components, sufficient for the application of the factor model (Table 1). The analysis results showed that most of the variables connected with each factor were well defined. The values for the factor weights of the studied variables connected to each of the PCs are shown on Table 1. It was determined that for Kardzhali reservoir PC1 included a substantial part of the variables connected to Sd, nutrients, as well as T°C and O_2. The parameters O_2, NO_3-N, TN and PO_4-P had positive factor weight, and the Sd and T°C had a negative factor weight in the formation of PC1 (Table 1). The PC2 was associated with a positive weight with Cond. and NH_4-N, TN и PO_4-P. The variables pH, O_2, O_2% Ph_N and Ph_B had a negative weight. The weight of the variables Ph_N, Ph_B, Cond. and NH_4-N was positive for the formation of PC3. Positive weight in the PC4 had O_2, O_2%, NH_4-N and COD_{Mn}, while for PC5 the variables include only TP and COD_{Mn}. The Ph_N and Ph_B had a negative weight in the PC4.

The variables with the highest level of significance for the development of phytoplankton in the Dospat reservoir according to correlation coefficients include: Sd, Cond., NO_3-N, TN, TP, COD_{Mn} and TVC. The calculated correlation coefficients for all of the variables with the exception of TVC had negative values. The results of the correlation matrix between environmental factors and the phytoplankton are shown in Table S3. The application of the PCA showed that the first main factors covered 79.91% of the total variance and again confirmed that they form the principal components sufficient for the application of the factor model (Table 2). The results showed that the first principal component (PC1) explained 30.59% of the total variance. Positive weights in the formation of PC1 had the variables Cond., NO_3-N, TN, PO_4-P and TP, while Ph_N, Ph_B, pH, O_2 and TVC had a negative weight. The PC2 represented 20.11% of the variance. Positive weight in the formation of the component had O_2%, NO_3-N, TN, and PO_4-P. The weight of Sd had high negative values. The variables O_2 and O_2% had significant positive factor weight and the NH_4-N had a negative dependency with the PC3 which explained a total of 13.59% of the variance. The PC4 was formed by the variables T°C, NH_4-N and TP and represent 8.96% of the variance. Total phosphorus (TP) had the highest weight in the formation of the last principal component (PC5), which explained 6.69% of the variance (Table 2). The results from our study have demonstrated the reliability of the PCA method in the process of determination of the main factors influencing the phytoplankton dynamics in the aquatory of Kardzhali and Dospat reservoirs.

Discussion

The PCA seeks to establish combinations of variables that can describe the main trends for a particular matrix observed during the study. This statistical method is designed to transform the original data set in a new, unrelated to each

Table 1
Factor matrix obtained by the method of principal components analysis for Kardzhali Reservoir

N	Indicators	Main components				
		PC1	PC2	PC3	PC4	PC5
1	Ph_N ($x10^{-6}$ cells.L^{-1})	0.226	<u>-0.538</u>	<u>0.645</u>	<u>-0.408</u>	0.223
2	Ph_B (mg.L^{-1})	0.243	<u>-0.495</u>	<u>0.672</u>	<u>-0.383</u>	0.243
3	Sd (m)	<u>-0.636</u>	<u>0.546</u>	0.378	-0.032	-0.159
4	T (°C)	<u>-0.897</u>	-0.262	0.081	0.161	-0.013
5	Cond. (μs/m)	-0.352	<u>0.712</u>	<u>0.514</u>	0.173	0.027
6	pH	-0.224	<u>-0.672</u>	-0.032	0.22	0.287
7	O_2 (mg.L^{-1})	<u>0.685</u>	<u>-0.514</u>	0.113	<u>0.401</u>	-0.149
8	O_2 (%)	0.347	<u>-0.674</u>	0.153	<u>0.549</u>	-0.111
9	NH_4-N (mg.L^{-1})	-0.006	<u>0.626</u>	<u>0.568</u>	<u>0.402</u>	0.023
10	NO_3-N (mg.L^{-1})	<u>0.835</u>	0.387	-0.224	-0.119	0.037
11	TN (mg.L^{-1})	<u>0.829</u>	<u>0.424</u>	-0.193	-0.104	0.038
12	PO_4-P (mg.L-1)	<u>0.639</u>	<u>0.479</u>	0.258	0.21	0.138
13	TP (mg.L^{-1})	-0.083	0.345	-0.239	-0.006	<u>0.764</u>
14	COD_{Mn} (mg.L^{-1})	-0.41	-0.094	-0.224	<u>0.373</u>	<u>0.445</u>
15	TVC (cfu.L^{-1})	<u>-0.565</u>	-0.091	-0.215	-0.282	-0.153
Percentage of the total variation,%		29.13	24.44	12.99	8.87	7.2
Cumulative percentage of the total variation,%		29.13	53.57	66.57	75.43	82.63

Table 2
Factor matrix obtained by the method of principal components analysis for Dospat Reservoir

N	Indicators	Main components				
		PC1	PC2	PC3	PC4	PC5
1	Ph $_N$ (x10^{-6} cells.L^{-1})	-0.752	0.309	-0.278	0.149	0.369
2	Ph $_B$ (mg.L^{-1})	-0.738	0.327	-0.305	0.145	0.354
3	Sd (m)	0.383	-0.787	0.249	0.059	0.087
4	T (^{o}C)	-0.094	-0.262	-0.107	0.534	-0.6
5	Cond. (µs/m)	0.558	0.028	-0.213	-0.365	-0.184
6	pH	-0.63	-0.294	0.408	-0.32	-0.037
7	O_2 (mg.L^{-1})	-0.416	0.543	0.631	0.25	-0.1
8	O_2 (%)	-0.482	0.378	0.648	0.316	-0.175
9	NH_4-N (mg.L^{-1})	0.315	0.107	-0.649	0.416	-0.154
10	NO_3-N (mg.L^{-1})	0.701	0.532	0.211	0.002	0.099
11	TN (mg.L^{-1})	0.736	0.538	0.106	0.074	0.073
12	PO_4-P (mg.L-1)	0.475	0.754	-0.089	0.064	-0.069
13	TP (mg.L^{-1})	0.611	-0.227	0.144	0.429	0.456
14	COD_{Mn} (mg.L^{-1})	0.461	-0.527	0.406	0.351	0.214
15	TVC (cfu.L^{-1})	-0.515	-0.348	-0.305	0.291	0.032
Percentage of the total variation,%		30.59	20.11	13.59	8.96	6.69
Cumulative percentage of the total variation,%		30.59	50.71	64.29	73.25	79.94

other indicators, called principal components that are linear combinations of the original variables (Shrestha and Kazama 2007; Wu et al., 2014). The PCA is a useful tool which makes it possible to identify relationships between species and to describe their seasonal changes (Garate-Lizarraga and Beltrones 1998). Based on the correlation analysis, factors with the most significant impact on the development of phytoplankton in this study for Kardzhali reservoir were Sd, Cond., pH, O_2, O_2%, NH_4-N, TN, PO_4-P, TP and TVC. The results demonstrate the crucial role of the macronutrients availability for the phytoplankton communities. These results are supported by earlier studies of the Kardzhali reservoir conducted between 2009-2012 (Dochin et al., 2015). The authors established that, based on Pearson correlation

Table S3
Pearson correlation matrix of the physico-chemical parameters and phytoplankton in Dospat Reservoir 2011-2012

	Ph $_N$	Ph $_B$	Sd	T^{o}C	Cond.	pH	O_2	O_2%	NH_4-N	NO_3-N	TN	PO_4-P	TP	COD_{Mn}	TVC
Ph $_N$	1														
Ph $_B$	0.987**	1													
Sd	-0.501**	-0.519**	1												
T^{o}C	-0.001	0.009	0.147	1											
Cond.	-0.353**	-0.333**	0.171	-0.073	1										
pH	0.228*	0.194	0.012	0.006	-0.291*	1									
O_2	0.290*	0.276*	-0.414**	-0.055	-0.327**	0.249*	1								
O_2%	0.269*	0.253*	-0.281*	0.061	-0.385**	0.321**	0.961**	1							
NH_4+	-0.082	-0.066	-0.147	0.16	0.15	-0.587**	-0.301**	-0.295*	1						
NO_3-N	-0.353**	-0.348**	-0.056	-0.189	0.309**	-0.445**	0.071	-0.062	0.051	1					
TN	-0.359**	-0.352**	-0.078	-0.16	0.326**	-0.528**	0.023	-0.106	0.206	0.988**	1				
PO_4-P	-0.105	-0.076	-0.428**	-0.139	0.317**	-0.541**	0.166	0.014	0.289*	0.632**	0.664**	1			
TP	-0.352**	-0.355**	0.455**	-0.03	0.143	-0.352**	-0.203	-0.229*	0.192	0.340**	0.363**	0.124	1		
COD_{Mn}	-0.444**	-0.462**	0.698**	0.121	0.059	-0.077	-0.159	-0.091	-0.027	0.103	0.097	-0.147	0.634**	1	
TVC	0.352**	0.331**	0.036	0.212	-0.279*	0.265*	-0.061	0.042	0.111	-0.476**	-0.449**	-0.482**	-0.147	0.153	1

*Correlation in significant at the 0.05 level (2-tailed)
**Correlation in significant at the 0.01 level (2-tailed)

coefficients, the parameters with the highest level of significance influencing the spatial and temporal distribution of the phytoplankton include pH, O_2, Sd and Cond. It is in agreement with the statement of Wu and coworkers (2014) that the nutrient composition and concentration is perhaps the driving force for the phytoplankton development. Ognjanova-Rumenova and coworkers (2013) also established that Sd, T°C, pH, and O_2 were the most important environmental factors that determined the distribution of diatoms in summer and autumn in Zhrebchevo reservoir and for the Koprinka reservoir with greatest significance were determined to be the Cond., Ca^{2+} and HCO_3^-. Similar dependencies were observed in our previous studies on the microbial community dynamics in the water column of Kardzhali reservoir (Iliev, 2014). The water temperature is an important abiotic factor effecting the biotic parameters of aquatic ecosystems, such as species composition and physiological activity of microbial communities (Zmyslowska and Golas 2003; Zmyslowska et al. 2001). According to Patra et al (2009) and Hossain et al (2012) the impact of nitrogen increases with the increase of the nutrient loading of water bodies. According to Kocer and Sen (2014) PCA analysis is a suitable instrument for the determination of the effect of T°C, pH, suspended solids, NO_3-N and Si on the abundance and distribution of phytoplankton. Other studies on the seasonal and spatial changes in phytoplankton established similar relationship between the concentration of dissolved solids, T°C, Cond. and pH and the dynamics of the communities (Lira et al., 2011). The application of the PCA in our study suggested that the variables with the highest positive weight in the formation of the principal components include O_2, NO_3-N, TN и PO_4-P. On the other side Sd, T°C and TVC have negative weight in the same PC. The variables with the high weight in the PC formation for Kardzhali reservoir on one side are responsible for the phytoplankton development, but on the other side they could be used as an indicator for allochthonous water inflow in the aquatory of the water body. The high weight of negative factors such as T°C and positive factor weight of O_2 in PC1 is an indication that this factor reflects the seasonal effect of water temperature on the phytoplankton communities. The negative correlation of the O_2 with the T^0C was not unexpected, since the oxygen solubility reduces with the elevation of the temperature. On the other side abundant phytoplankton growth leads to a reduction of Sd i.e. transparency is inversely related to the abundance of the phytoplankton. The factors with a negative weight in the formation of the PC2 include pH; O_2; Ph_N and Ph_B.

According to Shrestha and Kazama (2007) such results are related to the formation of anaerobic conditions in the water column. The presence of a high organic load in such environment results in the formation of ammonia and organic acids, which leads to the reduction of pH. The values of the pH are a suitable indicator for the organic load in the water bodies (Parinet et al., 2004). The increase in the phytoplankton abundance and biomass can also lead to the increase in pH and O_2 values as well as a decrease in Sd as a consequence of the photosynthetic activity of the algae community (Straskraba and Tundisi 1999; Wang et al., 2007).

The PC3 was formed by the positive weights Ph_N, Ph_B, Cond., and NH_4-N, demonstrating it's primarily association with the phytoplankton development. The electrical conductivity, which is part of the PC3, is a good pollution indicator (Parinet et al., 2004). In PC4 variables with positive factor weight are O_2, O_2%, NH_4-N and COD_{Mn} with Ph_N and Ph_B having a negative weight. The PC4 is closely linked with the phytoplankton. This is supported by our findings of the presences of direct feedback between NH_4-N and the phytoplankton abundance. It can be explained with the fact that ammonium nitrogen is the preferred source of nitrogen for phytoplankton (Straskraba and Tundisi 1999). Oxygen concentration in reservoirs depends on a number of processes such as: phytoplankton primary production and breathing, oxygen concentration and temperature of the water inflow, phytoplankton sedimentation and decomposition speed. Concentration and decomposition of the organics in the sediments and the resulting formation of anoxigenic hipolimnion layer, as well as the overturn conditions (Straskraba and Tundisi 1999). According Sahu and coworkers (2012) the main reason for the correlation between O_2 and Ph_N and Ph_B in the principal component, as the established in our research, is the ratio between phytoplankton respiration and photosynthesis. The elevated respiration can result in oxygen depletion.

The last PC for Kardzhali reservoir is formed mainly by the factor weights of TP and COD_{Mn}. The PC5 is closely related with the organic matter concentration, and hence water quality. The high factor weight of the TP showed its significance as a limitation factor for the phytoplankton abundance. It makes it a reliable indicator of the trophic status of the water body. Measurements of TP in the water include the amount of phosphorus contained in the phytoplankton and other aquatic organisms. For this reason, it gives a better idea of the trophic status of the environment in the event of a mass development of phytoplankton (Parinet et al., 2004). Our results have demonstrated the complex interactions between the studied environmental factors and phytoplankton communities in Kardzhali reservoir.

Multivariate analysis showed that the interactions between phytoplankton and abiotic indicators are strongly associated with the temporal heterogeneity. Such correlation creates the possibility to anticipate and clarify the model of phytoplankton variability based on some physico-chemical and biological parameters (Wang et al., 2007). The model discloses the linear relationship existing between a certain set of variables (Sahu et al., 2012), and it is a useful tool which enables the identification of intra- and interspecies relationships and to describe their seasonal dynamics (Garate-Lizarraga and Beltrones 1998). The application of factor analysis could distinguish differences between the variables of the environment and anthropogenic factors that affect phytoplankton community (Sun et al., 2011). This confirms the usefulness of the multivariate statistical analyses in understanding the interaction between environmental factors that affect planktonic communities in highly complex systems (Wang et al., 2007).

The results obtained in our previous study (Dochin et al., 2015) of Dospat reservoir for the period 2009-2012 revealed that among the most significant environmental factors influencing the abundance and spatial distribution of the phytoplankton are Sd, O_2, O_2% и Cond. Similar data have been published in a numerous studies, which have demonstrated significant correlations between the Ph_B, O_2, Sd and pH (Long et al., 2013; Wang et al., 2007). Based on the obtained correlation coefficients from the statistical analyses in our study NO_3-N, TN, TP, COD_{Mn}, TVC, Sd and Cond. were identified as the variables with highest impact on the phytoplankton in Dospat reservoir. Along with the TVC parameter they have a significant negative correlation with the Ph_N and Ph_B parameters. This indicates that these variables have the greatest impact on the development of phytoplankton and the TVC in the Dospat reservoir over the period and confirm the data from the correlation analysis. Such relationships in different water bodies have been analyzed by other authors (Onyema 2007; Dochin et al., 2015). The results from the application of factor analysis and in particular the method of the principal components for Dospat reservoir revealed five main factors that explained a total of 79.91% of the variance. The variables Cond., NO_3-N, TN, P-PO_4 and TP had high positive weight as factors forming the PC1. The variables with negative weight for the same component include Ph_N, Ph_B, pH, O_2 and TVC. The results showed that PC1 is associated with the dynamics in the microbial and phytoplankton communities in the reservoir and it also incorporates the nutrients as limiting factors. Similar results have been reported by Wang and coworkers (2007). According to the authors the Ph_B has significant positive correlation with TN and TP and negative correlation with pH, O_2 and Sd, which underlines the limiting effect of the nutrient concentration on the phytoplankton growth. The PC2 was formed by the O_2%, NO_3-N, TN and P-PO_4 as variables with positive weight and Sd as a variable with significant negative weight. This suggests that PC2 is related to the nutrients concentration as a food base for the primary producers. The variables O_2 and O_2% on one side and NH_4-N on the other had the higher positive and negative weight in the formation of PC3 respectively. PC3 is also related to phytoplankton development, regarding the relationship between photosynthesis and respiration, and ammonia assimilation. The variables T°C, NH_4-N and TP had positive weight in PC4. Water temperature, TP concentrations are considered to be major factors for the development of the phytoplankton (Wang et al., 2007). The PC5 includes TP as a positively related variable and T°C as a negative related variable. These results are similar to studies of other authors (Buric et al., 2007), which show that the nutrients and the T°C are the most important factors with respect to changes in the structure of phytoplankton communities. Data from our study suggest that physical factors and key nutrients are equally important in controlling the dynamics and structure of phytoplankton in the Dospat reservoir.

Conclusions

In the present study, we have used PCA analysis for the evaluation of the spatial and temporal interactions of the phytoplankton with the environmental factors in Kardzhali and Dospat reservoirs. A total of 15 parameters were analyzed as independent variables in both reservoirs. The results from the PCA for Kardzhali reservoir suggested that the 15 variables are grouped in five principal components which explained 82.63% of the total variation. The acquired data pointed out Sd, Cond., pH, O_2, O_2%, NH_4-N, TN, PO_4-P and TVC as variables with highest impact on the phytoplankton community in the reservoir. The studied variables for Dospat reservoir were reduced to five principal components, covering 79.91% of the total variance. The results from the PCA identified Cond., pH, NO_3-N, TN, PO_4-P, TP, COD_{Mn} and TVC as the most significant variables. Our study confirms the reliability of the multivariate statistical methods for the analysis and interpretation of complex data sets used for identification of the factors with the greatest weight and impact on the quantitative, spatial and seasonal phytoplankton growth in heavily modified water bodies.

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