Arch. Biol. Sci., Belgrade, 62 (4), 1083-1087, 2010 DOI:10.2298/ABS1004083Z

GEOGRAPHICAL AND BIOLOGICAL ANALYSIS OF THE WATER QUALITY OF BOVAN LAKE, SERBIA

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Abstract — In this work we performed a complex geographical analysis of the Bovan Lake basin, Serbia, as well as an analysis of the physical, chemical and biological parameters of water reservoir during a one-year period. The basic sanitary characteristics and physical, chemical and biological parameters, necessary for understanding locality conditions, were studied, and the saprobity index, class of quality, index O/H, degree of saprobity, degree of trophicity and category based on the phosphatase activity index (PAI), were determined. Our results classify the ecosystem as polytrophic. The degree of saprobity is oligosaprobic - beta mesosaprobic, with a catarobic degree in winter, classifying the water as III - IV class of quality. Due to the presence of organic residues, a domination of heterotrophic bacteria in comparison to oligotrophic bacteria is evident. The ability of autopurification is weak. The results indicate the need for continual monitoring of the water quality and environmental protection of Bovan Lake.

Key words: Bovan Lake, geographical parameters, organic pollution, biological parameters, water quality, Serbia

UDC 502/504(497.11):908

INTRODUCTION

Bovan Lake is an artificial reservoir situated in the middle flow of the Moravica River (Figure 1), Serbia. The reservoir was formed in the period 1978-1984 in the Bovanska Gorge, in front of a 52 m-high earthen-concrete dam with a volume of 297.000 m^3. At the peak of elevation (261.5 m), the net volume of the lake is 58.75 x 10^6 m^3, the area of water mirror 410 ha, width 500 m and length 8 km (Milinčić et al*.,* 2007*;* Milinčić*,* 2009). The area of the reservoir's basin in partition profile is 552 km^2, and at the peak of elevation 434 km^2.

The Bovan reservoir was planned as a multi-functional system, with the primary aim of regulating the basin of the Morava River and protecting the Đerdap I reservoir. Its important functions are to maintain silt and flooding waves, enrich small waters, produce hydro-energy, etc. The reservoir has a significant potential for water supply of settlements in the valley of the South Morava and the Morava. Although it was not considered for these purposes in the stage of planning and projecting, the water treatment plant "Bresje" and transmission system have been added, and the reservoir serves for the water supply to the settlements in parts of the districts of Aleksinac, Sokobanja, Ražanj, Paraćin and Kruševac (Milinčić, 2009).

In this paper we performed a complex geographical analysis (geological material - relief - climate - hydrology - pedology - vegetation) of the Bovan Lake basin, as well as analysis of the physical, chemical and biological parameters of the reservoir water during a one-year period. The studied locality (L-1) is situated 100 m from the mouth of the River Moravica as it enters the artificial reservoir (Fig. 1). Because of the proximity of the estuary waters, the locality is exposed to the influence of complex eco-geographic processes in the basin, possibly causing fluctuations in the studied parameters. The combining of geographical and biological methods offered an insight into the qualitative and quantitative geographic characteristics which influence the biological characteristics of water of the studied reservoir (Munster and Chrost, 1990).

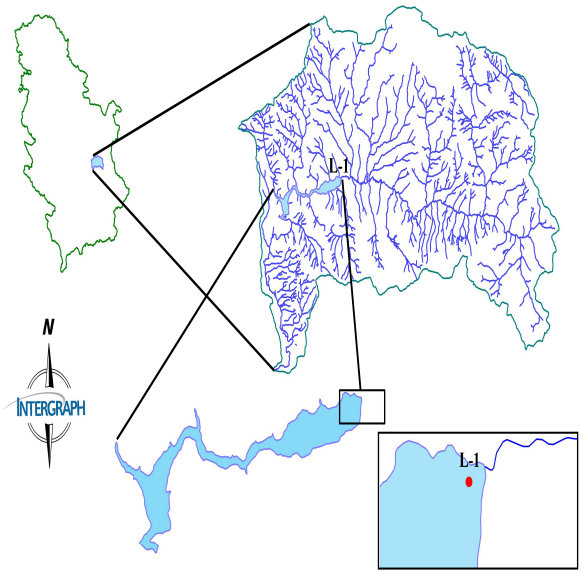

Fig. 1. Geographic position of Bovan Lake basin and the location of studied locality (L-1)

MATERIALS AND METHODS

Samples of water were collected in February, May, October and December 2004, from a depth of 30 cm. The time from sampling to the beginning of the analysis was not more than seven hours. In winter, due to the inaccessible terrain, samples were kept in the fridge and analyzed as soon as possible. The following microbiological, biological and biochemical parameters and groups were analyzed using standard procedures (Greenberg, 1989): the most probable number of coliform bacteria (MPN), fecal coliform bacteria (FCB), sulfite-reducing clostridia (SRC), *Proteus* sp., *Pseudomonas aeruginosa, Enterococcus faecalis, Bacillus* sp., aerobic mesophylic bacteria (AMB), total heterotrophic bacteria *sensu lato* (HB), oligotrophic bacteria (OB), amylolytic bacteria (AB), proteolytic bacteria (PB), saccharolytic bacteria (SB), lipolytic bacteria (LB), phytoplankton species, chlorophyll-a concentration and phosphatase activity. On the basis of those parameters we determined the saprobity index, class of quality, index O/H, degree of saprobity, degree of trophicity and category based on the phosphatase activity index (PAI) (Matavulj et al. 1990). We also studied physical and chemical characteristics: temperature, pH, turbidity, specific conductivity, total dissolved substances (TDS), dissolved oxygen, oxygen saturation, consumption of $KMnO_4$, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Greenberg, 1989).

In our geographic analysis of the basin we used geological, pedological and topographic maps 1:50,000, as well as the data of the Republic Hydrometeorology Institute (RHMZ), Belgrade, obtained from the hydrometeorology station Sokobanja.

RESULTS

Geographic analysis of Bovan Lake

A tectonic view of the Bovan Lake basin represents a depression which was formed by lowering the terrain along the Sokobanjski, Ozrenski, Sesalački, Rtanjski and Poružnički faults and Gola Mountain (Atanacković, 1977; Zeremski, 2002; Radivojević, 2008). The lowering of the terrain along the faults was much larger in the western part of the basin. The above-mentioned faults determined the direction of the location of the reservoir, its morpho-physiognomic characteristics and predisposed the hydrographic network, which spreads in a fan-shaped way from the mouth of the Moravica River into the reservoir. The Moravica River is the main hydrographic artery in the basin, accepting the waters of the six tributary rivers and seven streams.

The basin is mostly represented by sedimentary rocks, crystal slate and volcanic rocks. The middle part of the basin, near the reservoir, is mostly made of Neogene rocks: Pliocene sands, clays, and conglomerates. The porous limestone surface causes the aridity of the basin and the rapid movement of the water under continuous and intermittent streams.

According to the Köppen climate classification, the Bovan Lake basin has a moderate warm and humid CFWAX climate, which is complicated by orography. The mean annual air temperature is 10.6°C (Table 1). In winter, as a result of low temperatures

Table 1. Average monthly temperatures and quantity of precipitation in Bovan Lake basin, for the period 1990 – 2005

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	annually
°C	-0.3	1.1	5.4	11.2	15.8	19.0	20.8	20.6	16.2	11.0	4.8	1.4	10.6
mm	47	48	49	54	65	66	58	49	48	46	65	67	663

Table 2. Physical and chemical characteristics of Bovan Lake

Date, 2004	27 February	26 May	10 October	5 December
temperature (°C)	4.0	18.0	15.0	10.0
pH	7.72	8.47	7.25	7.90
specific conductivity (μS/cm)	236	147	263	211
TDS (mg/l)	207	127	246	186
O_2 (mg/l)	11.46	14.80	9.43	10.95
O_2 saturation (%)	87.28	155.14	92.90	96.64
$KMnO_4$ consumption (mg/l)	124.30	10.85	49.20	19.86
COD (mg/l)	31.07	2.70	12.30	4.96
BOD (mg/l)	8.24	7.30	8.21	3.63
Cl^- (mg/l)	15.0	14.0	-	12.0

(the mean January temperature is 0.3°C), the coastal parts of the lake are often frozen, which is the case with the mouth of the Moravica River.

The annual precipitation in the basin is 663 mm. The maximum is in December, while the minimum is in January (Table 1). The average annual insolation is 1862.4 h, with a maximum in July (267 h or 8.6 h per day) and minimum in December (148 h or 1.5 h per day). The vegetation period starts in March and lasts till November. The distribution of precipitation in the vegetation period is unfavorable.

In the Bovan Lake basin, forests and forestlands encompass 203 km2, pastures 95.94 km2 and meadows 58.8 km2. A big portion of agricultural land in the reservoir drainage basin (58.16%), mostly of IV, V and VI cadastral class, affects the increased erosion in the basin and the organic pollution of the surface, ground waters and the reservoir itself. Pollution is also increased by the wastewaters of the settlements in the basin.

Physical and chemical characteristics of Bovan Lake

As is the case in every reservoir, the water temperature of the Bovan Lake oscillates during the year, which is primarily caused by climate conditions, and above all, air temperature. The quantity of oxygen is the highest by the beginning of summer, when the water is overly saturated with oxygen. BOD is very high in all periods, as well as $KMnO_4$ (Table 2). The water reaction is mildly alkaline.

Table 3. Basic microbiological and biological characteristics of Bovan Lake

Date	27 Feb, 2004	26 May, 2004	10 Oct, 2004	05 Dec, 2004
MPN (cel/100ml)	>24000	>24000	>24000	>24000
FCB	*C. freundii* *E. coli*	*C. freundii* *E. aerogenes*	*E. aerogenes*	*E. coli* *E. aerogenes*
Proteus sp.	-	+	+	-
SRC	-	-	-	-
P. aeruginosa	+	-	-	+
E. faecalis	+	-	+	+
Bacillus sp.	*cereus*	*cereus*	*cereus*	-
AMB (cell/ml)	$8.04x10^3$	$1.30x10^3$	$9.80x10^2$	$1.23x10^3$
HB (cell/ml)	$2.24x10^5$	$2.06x10^5$	$4.45x10^4$	$4.48x10^4$
OB (cell/ml)	$8.40x10^4$	$8.17x10^3$	$1.54x10^4$	$3.19x10^4$
AB (cell/ml)	$2.60x10^2$	$4.00x10^1$	$4.50x10^1$	$8.00x10^1$
PB (cell/ml)	$9.50x10^1$	$2.24x10^2$	$2.00x10^1$	$1.10x10^3$
SB (cell/ml)	$1.78x10^4$	$5.45x10^3$	$5.75x10^2$	$5.90x10^1$
LB (cell/ml)	$4.28x10^2$	$3.36x10^2$	$6.50x10^2$	$1.25x10^1$
saprobity index	0	1.46	1.88	1.67
chlorophyll a (mg/m^3)	8.21	261.0	233.81	33.50
PAI (µmol/s/l)	2.94	2.24	1.28	0.62

+/- present/absent

Microbiological analysis of Bovan Lake

On the studied locality of the Bovan Lake the most probable number of coliform bacteria crosses maximum table values in the whole studied period, which indicates that the Bovan Lake is highly burdened. Fecal coliform bacteria are constantly registered, with the types most commonly present in reservoirs. Other indicators of fecal pollution are also present (*Proteus* sp., *Pseudomonas aeruginosa* and *Enterococcus faecalis*). Sulfite-reducing clostridia were not found. Aerobic mesophylic bacteria are numerous – up to several thousand per ml, often with *Bacillus cereus* species (Table 3). The phosphatase activity index varied during the studied period.

The quantity of chlorophyll varies considerably depending on the development of phytoplankton, and it reaches its maximum in May, thereby classifying the ecosystem as polytrophic (Pantle and Buck, 1955). The degree of saprobity is oligosaprobic - beta mesosaprobic, with a catarobic degree in February (Table 4).

In accordance with the increased quantity of organic residues, the number of physiologic groups of bacteria is increased. Heterotrophyic bacteria are very numerous, classifying this ecosystem as III – IV class of quality (Kohl, 1975). Oligotrophic bacteria are also numerous – up to several tens of thousands. The physiological groups of bacteria had large oscillations in number – from several tens of

Table 4. Phytoplankton species in Bovan Lake

	Phylum		
	Bacillariophyta	***Pyrrophyta***	***Chlorophyta***
	type/relative frequency of occurrence (according to Pantle-Buck)		
May	*Asterionella formosa/3*		
	Amphora ovalis/1		
October	*Nitzschya acicularis/2*		
	Navicula viridula/2		
	Gyrosigma acuminatum/5		
	Asterionella formosa/3		
	Amphipleura pellucida/2	*Ceratium hirundinella/5*	*Chlorococcum humiculum/5*
		Tetraedron regulare/1	
December	*Asterionella formosa/2*		
	Navicula viridula/1		
	Synedra acus/1	*Peridinium palatinum/Volvox aureus/2*	
		Ulothrix lenarrina/1	
		Scenedesmus acuminatus/1	
		Hematococcus pluvialis/1	
		Spyrogira porticalis/2	
		Closterium aciculare/1	

cells to several tens of thousands of cells per ml. The ability of autopurification is weak. The degrees of saprobity and trophicity are in mutual accordance. The highest quantity of chlorophyll matches the phase of intensive development and phytoplankton dying-off (Table 5). Due to the presence of organic residues, a domination of heterotrophic bacteria in comparison to oligotrophic bacteria is evident.

DISCUSSION

All surface waters show periodical changes in quality and quantity which are caused by natural and anthropogenic factors. The stability and characteristics of the reservoir waters depend on the characteristics of atmospheric, drainage and other kinds of water that feed the reservoir, as well as on the characteristics of the water-impermeable rocks the reservoir is located on, and those which are run through by the water flows that feed it, the presence and nature of soil layers in the basin, and the physical and chemical characteristics of tributaries, etc.

The decisive factor which influences the physical and chemical characteristics of the Bovan Lake and the studied locality (L-1) is the Moravica River. The waters of its tributaries have cut their riverbeds mostly into limestone and Neogene sediments, which directly affects the mineralization and alkalinity of the water in the Moravica River, and indirectly at locality L-1. In addition, erosive processes

Table 5. Derived biological characteristics

Date	27 Feb, 2004	26 May, 2004	10 Oct, 2004	5 Dec, 2004
Class of quality	III-IV	III-IV	II-III	II-III
Index O/H	0.38	0.04	0.35	0.71
Degree of saprobity	catarobic	oligosaprobic	mesosaprobic	mesosaprobic
Degree of trophicity	oligomesotrophic	polytrophic	polytrophic	mesoeutrophic
Categorization based on PAI	II-A	II-III	II-III	II-B

and vegetation significantly influence water quality in the reservoir. As a consequence of the removal of the humus layer, nutrients get into the water which encourages the growth of flora. Locality L-1 has a high consumption of $KMnO_4$ in all periods, which points to its burdening with substances of organic origin. This is caused by the emptying of the river Moravica and waters from the surrounding settlements, as well as soil removal and the penetration of artificial fertilizers and other chemical preparations from the surrounding agriculture areas into the river. In the first studied period (February) there was heavy rain caused an additional increase of the relevant chemical parameters (for example, consumption of $KMnO_4$).

Continual monitoring of water quality is a necessary measure in water protection, especially if it serves as a drinking-water supply. The most probable or total number of coliform bacteria, aerobic mesophylic bacteria, sulfite-reducing clostridia, *Enterococcus faecalis, Proteus* sp., *Pseudomonas aeruginosa* and other fecal bacteria are important indicators of the sanitary quality of the water. The water in the studied locality of the Bovan Lake is poor in all of the studied characteristics. Flow from the tributaries impact on the number of coliform bacteria that is over the maximum value throughout the vegetation period. Also, all fecal indicators and aerobic mesophylic bacteria are of the same origin.

In order to better understand some of the biological processes in water ecosystems, the presence of physiologic groups of bacteria that point to the qualitative and quantitative burden of water by substances of organic origin is often studied (lipolytic, cellulolytic, amylolytic and other). In accordance with the increased quantity of organic residues, the number of physiologic groups of bacteria is increased at the studied locality. The index of O/H is low, which is in accordance with relevant physical, chemical and microbiological parameters ($KMnO_4$, BOD, MPN, physiological groups of bacteria) (Petrović et al., 1998). This indicates the water's low ability of autopurification and confirms that it is burdened with organic and inorganic substances. The degrees of saprobity and trophicity are mutually in accordance.

So-called "young" reservoir lakes are mostly oligotrophic, with a small number of species and small biomass (Milanović, 1998). Our analyses point to the gradual "aging" of the Bovan Lake. Every spring and early summer the Moravica River disseminates a large amount of sediment that accumulates at the bottom of the Lake basin, leading to a decreased river outflow and, together with erosion and organic burden, changes in the physical and chemical composition of the water, as well as the degree of saprobity and trophicity. However, a one-year study period and single locality are not enough to determine the direction of changes and continual monitoring of water quality and environmental protection of Bovan Lake (Zlatković, 2006).

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