UDK: 556.1(497.11)

Seasonal aspects of water quality in the Grlište reservoir, Eastern Serbia

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Abstract. Over the period of one year assessment of water quality of the Grlište reservoir was done using physico-chemical and biological parameters. It was shown that the reservoir is monomictic and that stratification caused by the changes in water temperature dictated the movement and availability of nutrients. Bacillariophyta, Chlorophyta and Cyanobacteria were considerably more abundant then the remaining algal groups. Periodically elevated levels of nitrogen and phosphorous, and increased abundance of certain algal taxa indicated the development of eutrophication processes in Grlište reservoir. Results of biological and chemical analysis were compared to limit values defined by the Regulation for water quality.

Keywords: water quality, algal communities, Cyanobacteria, reservoir, Serbia

1. INTRODUCTION

Human activities has put an enormous pressure and stress on the quality of water in lakes and reservoirs. Human impact in and around the reservoir is felt on the unique physical and chemical properties of water, but biotic components of this ecosystem are also affected. Water quality is important in drinking water supply, irrigation, fish production, recreation and other purposes to which the water must have been impounded [6].

Due to urbanization, agriculture and industry eutrophication has become a global problem [20]. Process of eutrophication, which is caused by overenrichment with nutrients, principally phosphorus [1] leads to oxygen deficit, bad odors and algal blooms. Eutrophication of the Grlište reservoir started a year after the reservoir was formed, as result of the natural processes of succession and anthropogenic factors. The terrain on which the reservoir was created was originally used for agriculture [13].

Cyanobacteria has long been recognized as a water quality problem in lakes and reservoirs [4]. They attract a great deal of scientific and public attention because of the wide range of low molecular weight compounds (cyanotoxins) that they can produce [19]. As a consequence of increasing eutrophication on the global level, the occurrence of cyanobacteria is observed in many water bodies all over the world [18]. Frequent cyanobacterial proliferation was also observed in many water ecosystems in Serbia, natural lakes, accumulations, rivers and canals [17].

Numerous research covering various aspects of hydrology, geology and biology had been conducted in Grlište reservoir [7, 8, 9, 16, 17, 14, 2]. The research on phytoplankton and saprobiological characteristics of water in the reservoir Grlište was done during the period of 2001 to 2007.

The aim of this study is the assessment of water quality of the reservoir, primarily used as a water supply system by the city of Zaječar and nearby settlements, using some selected physico-chemical and biological parameters. The results will form the baseline for monitoring and tracking changes in the water quality as a result of the reservoir's natural dynamics over time or impact of men's activities on the reservoir and its watershed.

2. MATERIAL AND METHODS

Grlište reservoir is located 16 km southwest of the city of Zaječar (eastern Serbia), at an altitude of 187 m. It was created in 1989 by the damming of Grliška river – left tributary of Beli Timok. It stretches in the range of 28.5 km covering the area of 250 ha. Average water depth in the reservoir is 6 m, and maximum depth is 22 m at a point just before the dam (place of water intake). Maximum volume of water in the reservoir is 12000000 m^3. Reservoir receives water from a hilly basin, area of about 178 km^2, and two tributaries which supply the reservoir are the Lenovačka and Lasovačka river. Basin is located in the area with distinctive continental climate. According to yearly measurements average temperature during summer months was 27°C and during winter months was 4°C [13]. Mean annual amount of precipitation for the basin was 666.4 mm/m^2. In the phase of projecting, building and filling the main purpose of the reservoir was water supplying, although over time it has become polyfunctional.

Water sampling was conducted monthly during a period of 11 months. Due to inaccessibility of the sites – because of high snows and harsh conditions – sampling wasn't done during the December. Sampling was conducted by a vertical profile at the middle of the reservoir (N 43° 48.983' E 22° 13.212') and at the place of water intake (N 43° 48.743' E 22° 13.921'). At both places, using Ruttner water sampler, samples were taken by the height of a water column at the surface (0 m), 5 m, 10 m depth and at the bottom.

Measurements of temperature (T), pH and dissolved oxygen (DO) were done using water field kit MULTI 340i/SET (WTW, Weilheim, Germany). Transparency was measured with a Secchi disc. Total ammonia nitrogen (TAN) was analyzed with a spectrophotometer (Perkin Elmer, λ25/35/45 UV Vis) after direct nesslerisation. Nitrite nitrogen (NO_2^-) and total phosphorus (TP) were also measured on spectrophotometer . Nitrate nitrogen (NO_3^-) was measured by ion chromatography (Dionex 2020i). Total iron (Fe) and manganese (Mn) were measured on atomic absorption spectrometer (Perkin Elmer AAnalyst 200). Chemical parameters of water quality were given as mean values for the entire water column rather then for every sampling depth.

Algae and cyanobacteria were identified using Primo Star microscope (Carl Zeiss, Jena,Germany) at 400 × and 1000 × magnifications. Phytoplankton individuals were counted in a chamber (Hydro-Bios, Kiel, Germany) using inverted microscope Leica DM IL (Wetzlar, Germany) at 400 × magnification following the method of Utermöhl (1958).

According to ''Regulation on ecological and chemical parameters of surface waters and chemical parameters and quantitative state of underground waters'' (No. 74/2011) water quality of artificially created lakes, including reservoirs, can be classified into five categories: high (class 1), good (class 2), moderate (class 3), poor (class 4) and bad (class 5). Certain chemical and biological parameters were used to evaluate the ecological state of the lake.

3. RESULTS AND DISCUSSION

Extreme values of different physical and chemical water parameters of Grlište reservoir were shown in Table 1. Periods of high precipitation, mostly during spring time, were characterized by an increased discharge of the two tributaries – the Lenovačka and Lasovačka rivers. Suspended sediment and nutrient influx from nearby terrain also affected chemical and biological processes in the reservoir. The effect of waste waters from the village Leskovac, placed at the mouth of the tributaries, and small scale agricultural activities in the vicinity of the reservoir, were not assessed but we believe it affected water quality in the reservoir to a certain extent.

Table 1: Physical and chemical parameters of the Grlište reservoir

	Apr 12	May 12	Jun 12	Jul 12	Aug 12	Sep 12
Water temperature (°C)	10.1–16.9	9.9–20.9	11.1–28.9	11.8–28.1	11.0–26.9	10.3–21.3
Transparency (m)	1.4–1.6	1.2	1.7–1.9	1.4–1.5	2.5–3.1	1.9
Water level	192.02	193.07	192.97	192.66	192.18	191.54
pH	7.70–7.97	7.38–7.92	7.12–7.87	7.68–8.32	7.35–8.09	7.45–8.11
Ammonia (mg/l)	0.18–0.55	0.21–0.65	0.09–1.05	0.12–2.42	0.09–1.95	0.08–2.79
Nitrite (mg/l)	0.03–0.04	0.02–0.07	0.01–0.17	0.01–0.18	0.01–0.24	0.01–0.05
Nitrate (mg/l)	1.3–1.6	0.5–1.9	0.2–2.1	0.1–1.8	0.1–1.3	0.0–0.6
Total phosphorus (mg/l)	0.009–0.033	0.032–0.068	0.014–0.138	0.001–0.218	0.000–0.190	0.005–0.304
Dissolved oxygen (mg/l)	5.50–11.53	5.44–11.60	0.00–11.53	0.88–8.99	0.55–8.23	0.40–8.48
Iron (mg/l)	0.01–0.12	0.14–0.38	0.02–0.15	0.02–0.19	0.00–0.18	0.04–0.16
Manganese (mg/l)	0.00–0.05	0.00–0.05	0.00–0.80	0.00–1.04	0.00–0.95	0.00–0.95
	Oct 12	**Nov 12**	**Jan 13**	**Feb 13**	**Mar 13**	
Water temperature (°C)	7.3–16.9	9.3–11.3	4.1–5.6	3.5–4.0	6.4–6.9	
Transparency (m)	1.7	1.9	1.7	1.8	1.0–1.1	
Water level	190.87	190.53	191.28	191.75	192.93	
pH	6.71–7.62	7.39–8.01	8.26–8.40	8.32–8.35	8.25–8.36	
Ammonia (mg/l)	0.28–4.17	0.29–4.67	0.33–0.41	0.08–0.14	0.29–0.67	
Nitrite (mg/l)	0.00–0.34	0.01–0.06	0.03–0.05	0.03–0.06	0.05–0.08	
Nitrate (mg/l)	0.0–0.4	0.3–0.8	1.1–1.7	2.2–3.0	3.4–4.2	
Total phosphorus (mg/l)	0.003–0.424	0.003–0.665	0.029–0.070	0.035–0.072	0.042–0.080	
Dissolved oxygen (mg/l)	0.89–10.30	1.16–9.18	11.20–13.23	11.71–13.02	12.01–13.04	
Iron (mg/l)	0.00–0.68	0.11–0.95	0.07–0.14	0.10–0.19	0.23–0.31	
Manganese (mg/l)	0.00–1.28	0.00–1.14	0.02–0.03	0.00–0.04	0.00–0.09	

Stratification processes in Grliste reservoir started during late spring, but complete stratification was observed during summer. Two distinct strata could be distinguished – epilimnion and hypolimnion, with thermocline formed between a depth of 5 and 10 m. Seasonal stratification of the reservoir is caused by the change of the water temperature. It was found that the lake is monomictic due to pronounced stratification only during summer months. During summer small water inflow and high temperatures and insolation, together with well established stratification, leaded to an increased eutrophication levels in the reservoir. Vertical water mixing occurred during autumn, winter and early spring. Mean water temperature in spring was 11.51°C, in summer 18.93°C, in autumn 13.82°C and in winter 4.26°C.

Dissolved oxygen (DO) levels were influenced by water stratification. During summer months when phytoplankton biomass increased surplus oxygen production was limited only to surface water layers. Decay of organic matter consumes oxygen and this process is often intensified in summer, when aquatic organisms require more oxygen to support higher metabolisms. Due to intensified reduction processes deeper layers experienced a reduction of DO concentration, while the bottom was at times anoxic. Mixing periods were characterized by relatively stable DO levels. The highest DO values were recorded in March (12.45 mg/l), while the lowest DO was observed in August (4.17 mg/l). DO levels depend primarily on the relative magnitudes of photosynthetic oxygen generation and total plankton respiration [15]. Temperature inversely controls the solubility of oxygen in water, while there is a direct relationship between atmospheric pressure and DO.

Table 2: Number of recorded taxa and their percentage in the total number

Division	Number of taxa	Percentage (%)
Cyanobacteria	16	8.29
Bacillariophyta	111	57.51
Chlorophyta	48	24.87
Chrysophyta	1	0.52
Cryptophyta	3	1.55
Dinophyta	4	2.07
Euglenophyta	10	5.18

Phytoplankton growth is stimulated by nitrogen and phosphorous compounds [10]. Ammonium (NH_4^+), nitrite (NO_2^-) and total phosphorous (TP) concentrations were highest during autumn, while nitrates (NO_3^-) were higher during winter and early spring. Both nitrogen and phosphorous ions were concentrated near the bottom. It is known that high external phosphorous loading lead to nutrient accumulation in the sediment or internal P loading [12]. During mixing periods nutrients were moved upward and were more readily available to algal communities in the upper layers of the water column. Concentrations of Fe and Mn ions were also elevated near the bottom of the reservoir (Table 1).

Variation of phytoplankton abundance was seasonal (Fig. 1). Bacillariophyta and Chlorophyta were dominant in summer and Cyanobacteria were abundant in autumn. Those three groups also included the largest number of taxa (Table 2). Cyanobacteria were recorded during May, August, and October, with the highest peak in October (Fig. 2). The most abundant taxa were *Jaaginema subtilissimum* (Kützing ex Forti) Anagnostidis & Komárek, *Dolichospermum viguieri* (Denis & Frémy) Wacklin, L.Hoffmann & Komárek and *Komvophoron minutum* (Skuja) Anagnostidis & Komárek. All cyanobacterial taxa were found near the bottom of the reservoir. Cyanobacteria can develop in deeper parts of lakes because they can regulate buoyancy as a response to changing environmental conditions [19]. Some of the environmental factors that influence their development are high temperatures, high pH, low CO_2 and especially high phosphorous concentrations [3]. Phosphorous is also a limiting nutrient for cyanobacterial growth [11]. During summer and autumn months, due to the decomposition of organic matter, hypolimnion became an anaerobic environment. Anaerobic conditions can cause the release of the phosphorous from the sediment [5]. We believe that elevated TP and reduced DO level near the bottom of the reservoir were the main reason for cyanobacteria occurrence.

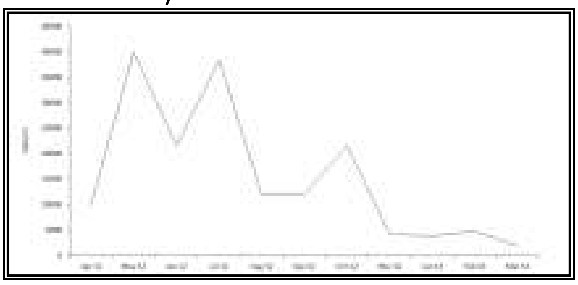

Figure 1. Total abundance of phytoplankton in Grlište reservoir

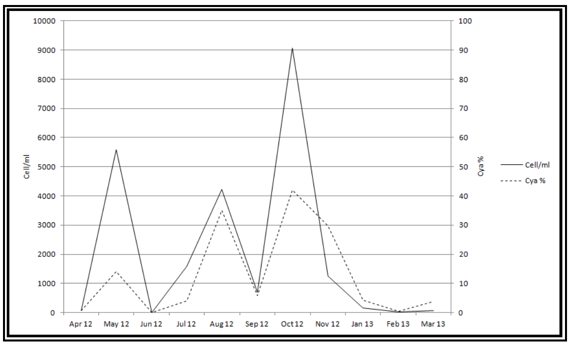

Figure 2. Seasonal abundance of cyanobacterial taxa and their percentage in total phytoplankton abundance

In the Grliste reservoir, the presence of potentially toxic cyanobacteria *Aphanizomenon flos-aquae* Ralfs ex Bornet & Flahault was also recorded. *Aphanizomenon* Morren ex Bornet & Flahault, 1886 is a bloom forming genus [4]. According to the World Health Organization's Guidelines For Drinking Water, anatoxin-*a*, saxitoxins, and cylindrospermopsins are produced by species of this genus [20]. Further eutrophication of the reservoir could lead to a higher development of potentially toxic cyanobacterial taxa.

Using water quality standards defined by the Regulation ecological potential classes for the Grlište reservoir had been determined (Table 3). Classification was done according to limit values for DO, NH_4^+, TP and Cyanobacteria percentage in the total abundance of phytoplankton. During summer and autumn months concentrations of DO and NH_4^+ indicated degradation of the reservoir's ecological potential down to class 4 and 5. According to TP levels the reservoir remained in class 2 throughout the year, although elevated TP was found near the bottom, especially during autumn. It was observed that the number of cyanobacterial cells and their proportion in the total abundance of phytoplankton overlaps (Fig. 2). According to the percentage of cyanobacterial taxa in total phytoplankton abundance, ecological potential belonged to class 4 in May, while in August, October and November it was class 5. Lower cyanobacteria percentage in May was due to the higher development of Bacillariophyta. Peak abundance of cyanobacteria was in October. Their

higher cell number in November was a result of a reduced development of other algal taxa.

Table 3: Water quality expressed as classes of ecological potential (1–5) according to the Regulation on ecological and chemical parameters of surface waters and chemical parameters and quantitative state of underground waters (No. 74/2011)

	Classes of ecological potential										
	Apr 12	May 12	Jun 12	Jul 12	Aug 12	Sep 12	Oct 12	Nov 12	Jan 13	Feb 13	Mar 13
Dissolved oxygen (mg/l)	2	2	4	4	5	3	3	2	2	2	2
Ammonia (mg/l)	3	3	3	3	3	4	5	5	3	3	3
Nitrate (mg/l)	2	2	2	2	2	2	2	2	2	2	3
Total phosphorus (mg/l)	2	2	2	2	2	2	2	2	2	2	2
Cyanobacteria (%)	2	4	2	2	5	3	5	5	2	2	2

This study has shown that several factors deteriorate water quality in the reservoir. In the past human activities around the reservoir and it's tributaries, together with possible internal P loading from the sediment, introduced an increased amount of nutrients which boosted plant growth. Nutrient enrichment also created favorable conditions for various algal species, some of which can negatively affect human and animal health. Increased nitrogen and phosphorous concentrations were connected to raised abundance of cyanobacterial taxa. According to the classification of water quality defined by the Regulation Grlište reservoir was placed between class 2 and 3 of ecological potential. Water quality fluctuated throughout the year, but in general it had been described as good to moderate. We propose more frequent monitoring of the Grlište reservoir in order to reduce eutrophication process and to provide clean and safe drinking water for local communities.

4. CONCLUSION

During summer months eutrophication of the reservoir was influenced by reduced water inflow, high temperatures, insolation and stratification of the water column. Oxygen production was limited to epilimnion, while nitrogen and phosphorous ions were concentrated near the bottom of the reservoir. Bacillariophyta and Chlorophyta were the dominant phytoplankton groups. Cyanobacterial taxa were recorded near the bottom during May, August, and October, with the highest peak in October. Their occurence was connected to elevated TP and reduced DO level. Grlište reservoir was placed between class 2 and 3 (good to moderate) of ecological potential according to the classification of water quality defined by the Regulation (No. 74/2011).

Acknowledgements

This study was financially supported by the Serbian Ministry of Education, Science, and Technological Development (Grant No. 176018).

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