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WATER QUALITY ASSESSMENT OF THE BORSKA REKA RIVER USING THE WPI (WATER POLLUTION INDEX) METHOD

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Abstract - The Borska Reka river (47 km long, 373 km^2 of basin area) is located in eastern Serbia and it is the biggest tributary of the river Veliki Timok. It is also one of the most polluted watercourses in Serbia. Using the data of the Republic Hydrometeorological Service of Serbia, the paper analyzes water pollution using the combined physical-chemical WPI index (water pollution index) over two periods: 1993-1996 and 2006-2009. The analysis of parameters showed significantly increased values of heavy metals (especially iron and manganese) which are indicators of inorganic pollution (primarily because of mining), but also increased values of organic pollution indicators (Biological Oxygen Demand-BOD$_5$, ammonium, coliform germs), as the result of uncontrolled domestic wastewater discharge.

Key words: The Borska Reka river, WPI (water pollution index), mining, copper, iron, manganese, BOD$_5$.

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INTRODUCTION

Much research has been devoted to the study of the influence of mining and the mining industry on the quality and pollution of surface waters. This problem is partly presented in the papers which examine environmental changes caused by mining, with special analysis of hydrological changes (Schrek, 1998, Razo et al., 2004, Rigina, 2002). Some theoretical research has considered the possible ways of solving the conflict between mining and its impact on the environment by defining adequate regulations (Bridge, 2000, Adler et al., 2007). Also, there are many papers and publications which analyze the water quality of certain water bodies (rivers and lakes) in large mine basins (Ashton et al., 2001, Rosner, 1998, Holopainen et al., 2003, Oli´as et al., 2004, Milentijević et al., 2010). The aforementioned research is mainly based on the sampling method and chemical analysis of parameters or satellite-image interpretation.

The mining development in eastern Serbia started in the first half of the 5th millennium BC, as verified by the archeological site "Rudna Glava" which is noted in scientific literature as the center of early European copper metallurgy. The copper mining mine "Bor" began in 1904 and was funded by foreign capital. However, after World War II, it became state property and is now the established company "RTB Bor Group". Metal production has increased in time and produces large quantities of waste products and therefore creates complex ecological problems. The written data have indicated that the environmental state in the town of Bor and its surroundings has been recorded in certain ways since 1908 when an area of 1250 ha was covered with dangerous substances (Stanković, 2004). Today, old-fashioned technologies which produce a large quantity of solid and liquid waste are mainly used in the mines. Besides the constant watercourse pollution by the wastewaters discharge, there are sometimes very dangerous accidents through flotation dams breaking.

The Borska Reka basin is located in eastern Serbia. It covers 373 km^2, which is about 8% of the total river basin of the Veliki Timok river. This river is to the left of the *Veliki Timok* into which it empties at the place Vražogrnac, and is the biggest tributary. It springs from the eastern slopes of the Veliki Krš and Mali Krš mountains (1148 m altitude) and it is 47 km long. Running towards the mouth, it receives several tributaries, among which are the Kriveljska river, Belorečka river, Slatinska river etc. The Slatinska river is taken as an extension of the Borska Reka river. The average annual discharge is about 3.22 m^3/s, the lowest is in August (1.65 m^3/s), and the highest is in February (4.90 m^3/s).

Map 1. Borska River Basin and profile Rgotina location

The *Borska Reka* river is one of the most polluted watercourses in Serbia; it is an out of water class river and without any traces of life. The basic pollution source in the Borska Reka basin is the mining-industrial complex "Bor" and untreated communal wastewaters. Numerous researchers study the problem of water quality and pollution in this river basin in the framework of environmental state analysis (Lekovski et al., 1997, Lekovski and Miljković, 1997, Jenić and Mitrović, 1992) or water course quality (Ristić and Ristić, 1991).

MATERIAL AND METHODS

The data from the Republic Hydrometeorological Service of Serbia on the Borska Reka river water quality were used, from two analyzed periods: 1993-1996 and 2006-2009. Such defined time sequences have enabled the determination of the differences and comparison of the river pollution levels formed in a ten-year period. Systematic analysis of the river water quality has been performed at the hydrological station profile Rgotina.

For determination of water physical-chemical parameters, different groups of standard international laboratorial methods are used: SRPS methods (for the dissolved oxygen, suspended substances, pH, ammonium and nitrites (NO_2-N)), APHA AWWA WEF methods (for sulfates (SO_4^{--}), iron (Fe) – dissolved, manganese (Mn) – dissolved, copper (Cu) – dissolved, lead (Pb) – dissolved, cadmium (Cd) – dissolved and orthophosphates (PO_4-P)) and EPA methods (for mercury (Hg) – dissolved and biological oxygen demand (BOD_5)).

The obtained data are used for water pollution level determination in river water according to WPI values (water pollution index). This is a combined physical-chemical index which makes it possible to compare the water quality of various water bodies (independent of the presence of pollutants) (Filatov et al., 2005). Therefore, it has wide application and it is used as the indicator of the quality of sea (Filatov. et al., 2005) and river (Lylko et al., 2001) water, as well as of drinking water (Nikoladis et al., 2008). The WPI represents the sum of the ratio between the observed parameters and regulated standard values:

$$WPI = \sum_{i=1}^{n} \frac{Ci}{SFQS} \times \frac{1}{n}$$

where C_i is the average annual concentration of the analyzed parameters obtained on river water quality data, which are sampled approximately once a month. The following parameters are taken into consideration: dissolved O_2, pH, suspended sediments, BOD_5, nitrites, orthophosphates, ammonium, metals (Fe, Mn, Hg, Cu, Pb, Cd), sulfates and coliform germs. QS represents the standard values for the I water quality class in Serbia, while *n* indicates the number of analyzed parameters in the research.

Table 1. Standards of used parameters

Parameter	Measurement unit	Quality standard
O_2	mg/l O_2	8
pH		8.5
Suspended matter	mg/l	10
BOD (biological oxygen demande)	mg/l O_2	2
Nitrite	mg /l	0.03
Orthophosphates	mg/l	0.005
Ammonium	mg /l	0.1
Iron	mg/l Fe	0.3
Manganese	mg/l Mn	0.05
Mercury	μg/l Hg	1
Copper	μg/l Cu	2000
Lead	μg/l Pb	50
Cadmium	μg/l Cd	5
Sulphates	mg/l	250
Coliform germs		2000

According to the obtained WPI values, the river water is classified into different classes (Table 2). If the value of WPI < 1, the watercourse is marked as pure, if WPI > 2, the watercourse is polluted, and if WPI > 6, the watercourse belongs to the group of heavily impure waters (Lylko et al., 2001).

Statistical data processing and graphic presentations in the paper are done in Microsoft Excel, and the cartographic method and Adobe Photoshop programs are applied for defining spatial relations.

Table 2. Water quality classification according to WPI (Lyulko et al., 2001)

Class	Characteristics	WPI
I	Very pure	≤0.3
II	Pure	0.3-1.0
III	Moderately polluted	1.0-2.0
IV	Polluted	2.0-4.0
V	Impure	4.0-6.0
VI	Heavily impure	>6

RESULTS

As has already been mentioned, in order to assess the pollution level of Borska Reka river in a longer period and to notice the trends, two four-year sequences in a ten-year period are analyzed in this paper: the first one 1993-1996 and the second 2006-2009. Annual WPI values in all the analyzed years indicate a high level of water pollution; therefore Borska Reka belongs to the VI category (heavily impure) with WPI values > 6.

According to Table 3, it can be concluded that the worst quality was registered in 1996 (average WPI value 26.4), which is far above the limit value of 6. The values of WPI index >10 were also registered in 1993 and 2008.

Observing the analyzed periods, it can be noticed that in some years during the 90s much higher levels of pollution were registered than in the analyzed period after 2000. However, the general state has not

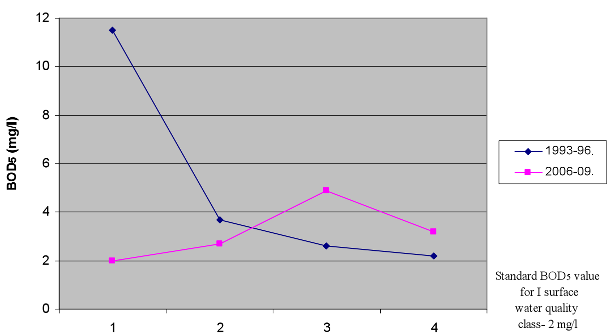
Table 3. Ratio of mean annual concentration and standards of the I water quality class for analyzed parameters

God.	O_2	pH	Susp. sed.	Nitri tes	Ortho ph.	Ammon.	Sulph ates	Fe	Mn	Hg	Cu	Pb	Cd	BOD_5	Colif. germ.	WPI
1993	1.12	0.86	9.56	0.50	1.00	89.60	0.12	16.73	49.60	0	2.29	1.06	0.65	5.73	4.65	12.23
1994	1.50	0.81	25.67	0.07	2.00	47.90	1.26	9.97	16.60	0	0.05	0.35	0	1.86	7.58	7.71
1995	1.02	0.77	19.72	0.17	1.60	64.20	0.23	8.90	38.80	2.43	0.31	0.17	0	1.28	4.48	9.80
1996	0.84	0.64	12.57	0.23	11.20	112.00	0.72	132.33	93.60	0	26.72	1.91	0.35	1.12	1.88	26.40
2006	1.35	0.65	28.50	0.10	2.00	10.90	2.01	1.26	74.60	1.00	7.31	0.23	1.74	0.98	6.33	9.26
2007	1.14	0.61	27.00	0.10	4.00	12.30	2.33	1.46	68.60	0.38	3.78	0.40	1.24	1.36	1.05	8.38
2008	0.97	0.56	44.50	0.19	2.00	14.50	1.65	2.06	64.20	0.10	3.52	0.92	1.12	2.42	65.00	13.58
2009	0.89	0.65	29.40	2.13	12.00	1.50	1.35	1.13	67.20	0.15	0.51	0.04	0.86	1.59	2.76	8.14

improved according to the WPI values, so a large degradation of this water resource is still present and it is often called "dead river".

Apart from the average annual WPI values which indicate the pollution level of this river, the analysis of the influence of some parameters on the pollution level is also important. As it can be noticed from data in Table 3, in both periods, 1993-1996 and 2002-2006, certain parameters (pH, nitrites, sulfates, lead, cadmium etc) are mostly within allowed limits of the regulated standard values for the I water quality class in Serbia and they do not have any influence on the pollution of Borska Reka river. On the other hand, the values of elements which are organic pollution indicators have increased considerably (BOD_5, ammonium, coliform germs) as well as the values of some heavy metals (especially iron and manganese).

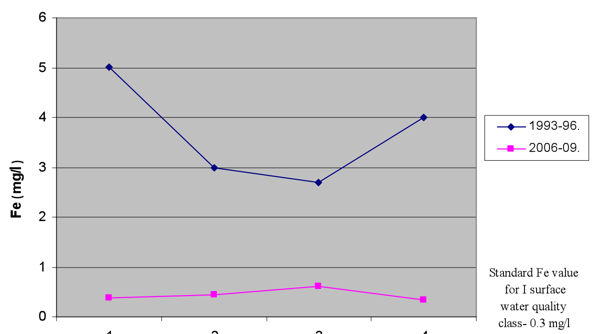
The increased number of coliform germs indicates considerable pollution which comes from communal wastewaters from households in the surrounding settlements. The increased values of BOD_5 characterize the biological activity of the wastewaters and represent the main organic pollution indicator (Graph 1). The cause of the increased values of the aforementioned parameters is certainly the presence of a communal landfill near to the town of Bor. It is located in an abandoned part of the pit mine where waste is disposed without any previous treatment or covering with soil after disposal. Besides, in the surroundings of the town and rural settlements there is a large number of uncontrolled trash dumps (unorganized landfills).



Graph 1. Mean annual BOD5 values

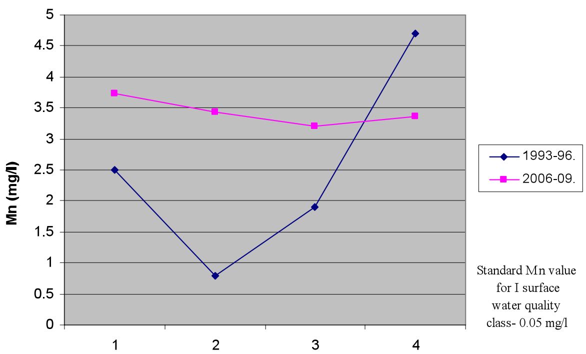
Although there is a copper mine in the Borska Reka basin, the measured copper values in water fluctuated in the analyzed periods. Following and increase in the values in 1993, the copper values were within allowed limits in the succeeding period. In the period from 2006, increased values of copper were constantly recorded until 2009 when they were within the allowed limits.

Unlike to the values of copper, the quantities of iron and manganese in the water during the 90s and 2000s were considerably higher than the allowed ones. The quantities of dissolved iron in the water were over 10 times higher than the allowed ones in the period 1993-1996. Certain changes can be noticed in the period 2006-2009, when the percent of iron in water was considerably lower, so the present quantities were slightly above the allowed ones (Graph 2). Increased iron values are the consequence of copper production from sulfide ores (chalcopyrite $CuFeS_2$) in the pyrometallurgical process in which different elements appear as by-products in dross, among which iron is in significant concentration.



Graph 2. Mean annual Fe values

According to Graph 3, the amount of manganese in Borska Reka river has constantly increased. During 1993, they were almost 50 times higher than the regulated values for the I water quality class in Serbia. Research in the period 2006-2009 has shown an increasing trend of manganese concentration in water, as opposed to iron which decreased. The values increased even 70 times more than the suggested ones. The cause for this is wide use of this element in the process of copper processing (the production of alloys and steel etc).



Graph 3. Mean annual Mn values

DISCUSSION

The water pollution problem in Serbia appeared in the middle of the 20th century, as a consequence of the sudden industrial development of the country and increasing urbanization. Particularly endangered are river basins in the areas of mining production; therefore the question of their protection and revitalization has become important.

In the Borska Reka basin several significant industrial zones can be singled out in which the mining industry dominates with capacities in the Mining-Industrial complex “Bor” (copper smelter and refinery, enameled copper wire plant, copper wire plant, foil production, equipment and parts manufacturing plant, sulfuric acid etc). Pollution of an inorganic origin mainly comes from mine’s wastewaters due to the technological processes of separating mineral goods and wastewaters from the tip heap. This is also confirmed by the WPI values obtained in researches. In all the analyzed years, the quality of the water has been in the category of heavily impure and it has a value of WPI>6. The worst water quality was recorded in 1996 and it had average WPI value of 26.4, which is far above the limit value of 6. Observing the analyzed periods, a higher level of water pollution has been noticed during the 90-ties in comparison to the period after 2000. However, the general state has not improved according to WPI values.

Considering that the pollution of Borska Reka river is a cross-border and regional problem and that it influences the quality and use of the Danube waters, the realization of plans and projects concerned with the control of the influence of mining production on watercourses has been initiated. Therefore, the Bor municipality has made a *Local Ecological Action Plan* which, among other things, plans to take some measures in the organization of mining-metallurgical production which will not impair the environment (Local Ecological Action Plan, 2003). The project *Campaign for the introduction of new technologies in mines of the Danube river basin,* which would reduce pollution by heavy metals and secure sustainable production has planned to arouse consciousness of the possibilities of sustainable mining production in the Danube river basin, in other words, of the need for new technology application in mining which will reduce watercourse pollution, in this particular case - the pollution of the Danube river basin with heavy metals (Group of authors, 2003). The objective of the project *The participation of local community in the control of pollution with mine waters* has been to provide information on mine waters and inform the interested parties (relevant decision makers, academic public and local community representatives) about the pollution problem which arise from active and abandoned mines.

Future priority tasks connected to the revitalization of degraded watercourses in the Borska Reka basin are: the introduction of technologies for wastewater treatment in mining; the construction of a system for communal and wastewater treatment; the revitalization of degraded watercourse coastal parts, and the education of the population about water protection. In this regard, the company “RTB Bor Group”, in the framework of future modernization of production, has planned to construct plants for the treatment of wastewaters from different sections. Water, purified in this way, should be returned to the process of production and in accordance with regulated standards.

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