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APPLICATION OF THE WATER QUALITY INDEX IN THE TIMOK RIVER BASIN (SERBIA)

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Abstract: The paper presents an analysis of water pollution carried out on the basis of the combined physico-chemical Serbian Water Quality Index (WQI) in the Timok River basin. The analysis covers various parameters (oxygen saturation, Five-Day Biochemical Oxygen Demand or BOD_5, ammonium ion concentration, pH value, Water Total Nitrogen or WTN, Total Suspended Solids or TSS, orthophosphate concentration, electrical conductivity, temperature and the fecal coliform bacteria parameter) the values of which were calculated for four hydrological stations within the basin. The data obtained at each measurement station were averaged using the annual arithmetic average mean. The annual WQI values were calculated for a twenty-five year period (1990–2014) and they were in the range between 12 and 92, which means that the quality of water varied, ranging from "very bad" to "excellent". The obtained results were interpreted and the watercourse quality was assessed using the comparison of water quality indicators according to the Serbian Classification of Surface Waters and the WQI method. The worst water quality was recorded in the Borska Reka River. Certain SWQI values are the result of water quality changes caused by wastewater from human settlements, industrial facilities, agricultural sources and illegal waste disposal sites in the basin.

Keywords: Water Quality Index; water quality; water pollution classes; Timok River

Introduction

The problem of river pollution in Serbia has become increasingly prominent since the mid-20th century as a consequence of the rapid industrial development of the country and rising urbanization. "Water is an essential element for all life forms, as well for the social and economical development of the mankind. It is a naturally regenerating medium, but its qualitative characteristics are vulnerable to polluters like waste, urban agglomeration, intensive agriculture and the lack of a good management in this field" (Nistor, Botez, Andronoiu, & Mocanu, 2012). The study of the quality and pollution of watercourses in the world is usually based on the application of various mathematical and statistical methods (Urošev, Milanović, & Milijašević, 2009; Milanović, Milijašević, & Brankov, 2011; Brankov, Milijašević, & Milanović, 2012; Pantelic, Dolinaj, Savic,

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Stojanovic, & Nadj, 2012; Takić, Mladenović-Ranisavljević, Vasović, & Đorđević, 2017). In recent years, the analyses of watercourse quality based on mathematical indexes have become increasingly common. Authors from all over the world use the Water Quality Index as a reliable indicator of watercourse pollution (Bordalo, Teixeira, & Wiebeet, 2006; Lumb, Halliwell, & Sharma, 2006; Bharti & Katyal, 2011; Jakovljević, 2012; Singh, Tiwar, Panigary, & Mahato, 2013; Tyagi, Sharma, Singh, & Dobhal, 2013; Ismail & Robescu, 2017).

The Water Quality Index (WQI) is a numerical value that shows a complex impact of relevant physical, chemical and microbiological parameters on water quality. This is an efficient method to indicate the current water quality and its trend in the observed area. The Water Quality Index was adopted by the European Union as a water quality assessment tool. In order to reduce the risk for aquatic ecosystems, especially water quality, the experience of developed countries should be used (Zhukinskii, 2003). In Serbia, this method was used in an analysis of the water quality of the Danube River and the Danube-Tisza-Danube channel system (Veljković & Jovičić, 2007; Milanović et al., 2011).

The present study presents an analysis of the water quality in the Timok River Basin. The Timok is the largest river in Eastern Serbia and the last tributary of the Danube in Serbia. The Timok River Basin is situated in the eastern part of Serbia, between 43.3° and 44.2° N and 21.6° and 22.7° E. Timok's confluence into the Danube is located on the border between Serbia, Bulgaria and Romania. It is formed by the joining of the Beli Timok, which flows from the southeast, and the Crni Timok, flowing from the southwest. The juncture of these rivers is located about two kilometres southeast of Zaječar, at an absolute height of 118 m (Milijašević, 2014).

Materials and methods

For the analysis of the watercourse quality in the Timok River basin we used the database of the Republic Hydrometeorological Service of Serbia. The study covers the established watercourse profiles in the basin (Figure 1) where systematic water quality analyses are carried out (approximately once a month): the Timok River (Čokonjar Watercourse Profile), the Borska Reka River (Rgotina Watercourse Profile), the Beli Timok River (Zaječar Watercourse Profile) and the Crni Timok River (Zaječar Watercourse Profile). The Serbian Water Quality Index (SWQI) examines the following parameters: oxygen saturation, Five-Day Biochemical Oxygen Demand (BOD5), ammonium ion concentration, Water Total Nitrogen (WTN), Total Suspended Solids (TSS), orthophosphate concentration, electrical conductivity and the fecal coliform bacteria parameter, which were all determined using the APHA, AWWA, WEF standard methods (American Public Health Association, American Water Works Association, & Water Environment Federation, 2012), and the pH value and temperature, which were measured by means of a pH metre and a thermometer. The data obtained at each measurement station were averaged using the annual arithmetic average mean. We thereby obtained a series of 25 values for three hydrological stations and a series of 23 values for one hydrological station for the period 1990–2014.

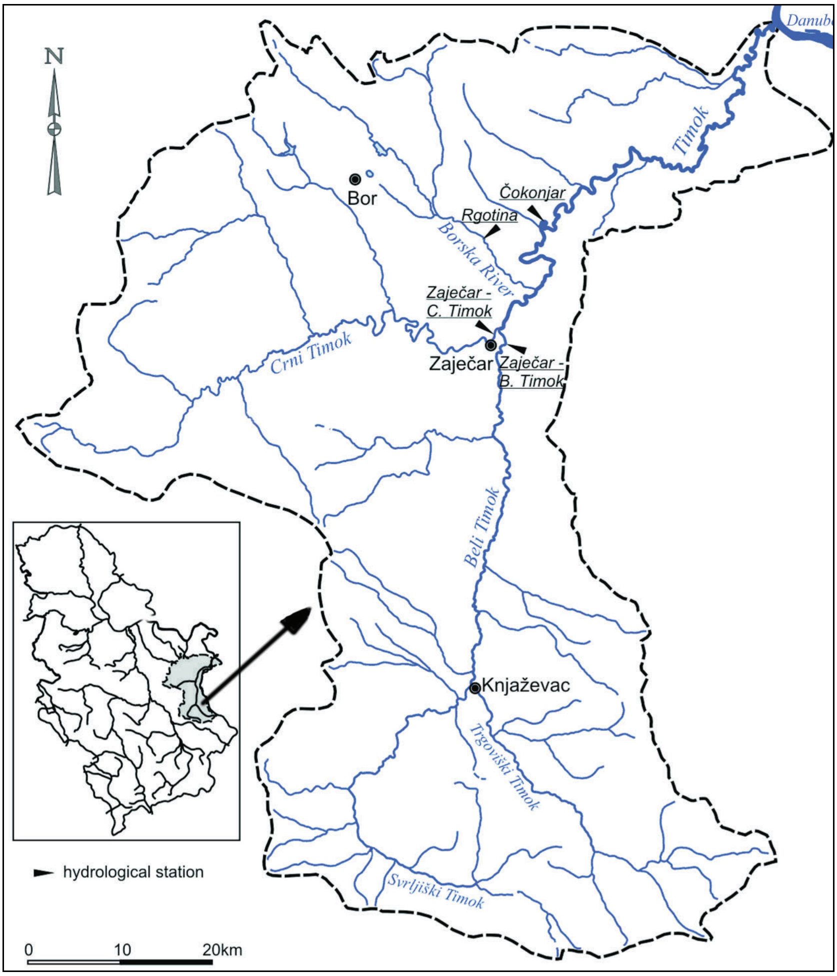

Figure 1: Location of the hydrological stations in the Timok River basin and the position of the basin in Serbia (Source: Made by the authors, 2018)

The Water Quality Index Method (WQI) combines the standardized values (qi) of the above-mentioned ten parameters, which describe the properties of surface waters, to calculate a single index value. The ten parameters have different relative significance for the overall water quality. Therefore, each parameter was assigned a weighting factor (wi) and a number of points in accordance with the threat they pose to water quality. By summing up the products of the qi and wi values we arrive at an index value of 100 as an ideal sum of the values of particular parameters. In case we miss the value of some parameter, the value of the arithmetically calculated WQI is corrected by multiplying the index with the 1/x value, where x represents the sum of the arithmetically calculated weighting factors of available parameters (Veljković, Lekić, & Jovičić, 2008).

The arithmetic formulation for the WQI is of the form:

$$WQI = \sum_{i=1}^{n} qi \cdot wi \qquad (1)$$

where WQI is the water quality index, and is a number on the continuous scale from 0 to 100, *n* – number of parameters, qi – the water quality of the *i*-th parameter, wi – the weight attributed to the *i*-th parameter (Veljković, 2000).

The obtained results were interpreted and a water quality assessment was made using the national water classification system and the original WQI method. Based on the SWQI, water quality is classified into five categories. The descriptive quality indicators for the WQI ranges were also determined (Table1).

Table 1: Classification criteria standards according to the Serbian Water Quality Index

Serbian WQI	Descriptor Category
90–100	Excellent
84–89	Good
83–72	Medium
39–71	Bad
0–38	Very Bad

Source: www.sepa.gov.rs

“Numerous water quality indices have been formulated all over the world which can easily judge out the overall water quality within a particular area promptly and efficiently. For example, US National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), and Oregon Water Quality Index (OWQI). These indices are based on the comparison of the water quality parameters to regulatory standards and give a single value to the water quality of a source" (Bharti & Katyal, 2011).

Results

The research results are presented in figures showing the estimated values of the water quality index for the observed hydrological stations (Figure 2). Each row gives annual WQI values for the following rivers: the Timok (Čokonjar Watercourse Profile), the Borska Reka (Rgotina Watercourse Profile), the Beli Timok (Zaječar Watercourse Profile) and the Crni Timok (Zaječar Watercourse Profile). The worst watercourse quality in the Timok River basin was recorded in 1994, when the annual average WQI values for three rivers fell into the category "bad". The 1994 Serbian Water Quality Index value for the Crni Timok River was somewhat higher, falling into the category "medium". The observed situation may be explained by an unfavourable hydrological situation, having in mind that the data collected for the majority of the hydrological stations show the lowest annual average flow rate over a 50-year period (1961–2010). The best water quality in the observed period was recorded in 2001. The SWQI value for the Borska Reka River remained in the "bad" range, whereas the index values for other rivers fell into the "excellent" category.

The calculated average SWQI values for the Timok River for the period 1990–2014 show significant oscillations in water quality. SWQI ranges between 65 and 90, which corresponds to the descriptive categories between "bad" and "excellent". The poorest water quality was recorded in the period between 1990 and 1995 ("bad"), whereas in 1995 it was significantly improved (a SWQI score of 84). During 1996 and 1997, water quality was good. The annual average SWQI values for the period 1998–2005 indicate an improved water quality, with SWQI scores above 84, whereas a slight decrease in water quality was observed since 2005. The water quality of the Beli Timok River in the period 1990–2014 mostly ranged between "medium" and "good". The poorest water quality was observed in 1994, when the SWQI score was 70 ("bad"), and the best SWQI value was recorded in 2001 – 92 SWQI ("excellent").

The best water quality in the Timok River basin was observed in the Crni Timok River: the calculated average SWQI values for the period 1990–2014 ranged between 76 and 92 – i.e., in terms of descriptive indicators, between "good" and "excellent". This indicates that there are significant oscillations in water quality.

An extremely bad water quality was observed in the Borska Reka River; this is, at the same time, the lowest score recorded in the basin. Throughout the observed period, annual SWQI values were below 76, which means that the water quality of the river in all years was "bad" and "very bad". These index values indicate a very high pollution level, which ranks the Borska Reka among the most polluted watercourses in Serbia and Europe and justifies the commonly used designator "dead river". The water quality of the Borska Reka significantly affects the pollution level of the Timok River (Ocokoljić, Milijašević, & Milanović, 2009; Milijašević, Milanović, Brankov, & Radovanović, 2011).

The lowest SWQI index score was recorded in 2013 — 12, indicating exceedingly high values of the analyzed parameters, which reached the following annual average scores: ammonium ion concentration — 4.56 mg/l, total nitrogen oxide — 12.89 mg/l, electrical conductivity — 1,876.3 µS/cm, pH — 4.8, oxygen saturation as low as 7.3% and Total Suspended Solids — 236 ml/l. In 2005 and 2014, the analysis of physico-chemical water quality parameters for the Borska Reka was not carried out and the 2005 and 2014 SWQI score could not be calculated. The average values of the analyzed parameters between 1990 and 2014 confirm the conclusion that the most unfavorable values of the indicators of the physical, chemical and microbiological water pollution were recorded in the Borska Reka. The highest percentage of the annual values that fall into the "excellent" category was recorded for the Crni Timok River, whereas the highest percentage of the scores designated as "very bad" were observed in the Borska Reka.

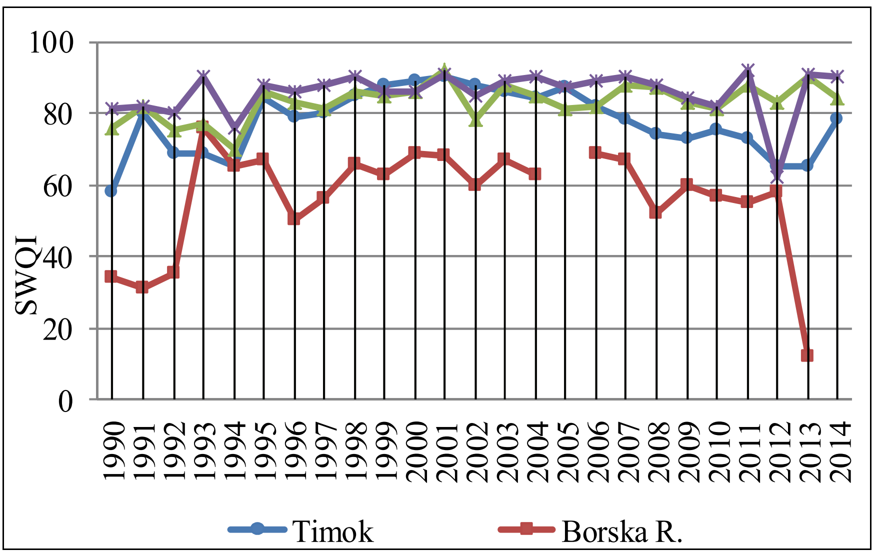

Figure 2: Serbian Water Quality Index values in the Timok River basin between 1990 and 2014

Figures 3 and 4 show the values of the BOD_5 and the ammonium ion concentration. These parameters are included in the SWQI calculation and they significantly contribute to the pollution of the waters in the Timok River basin. The BOD_5 value shows the biological activity of wastewater; it is the chief indicator of wastewater pollution. Higher BOD_5 values (in mg/l O_2) indicate a higher pollution with organic substances. The cleanest surface waters have a BOD_5 value below 2 mg/l O_2. The highest annual average BOD_5 values were recorded in the Borska Reka River: the average value for the 23-year period was 3.77 mg/l. The highest annual average value was recorded in 1991 — 15.6 mg/l. In the observed period, the annual average BOD_5 values in the Timok River ranged between 1.29 mg/l and 7.4 mg/l. The corresponding values for the Beli Timok and Crni Timok rivers were somewhat lower.

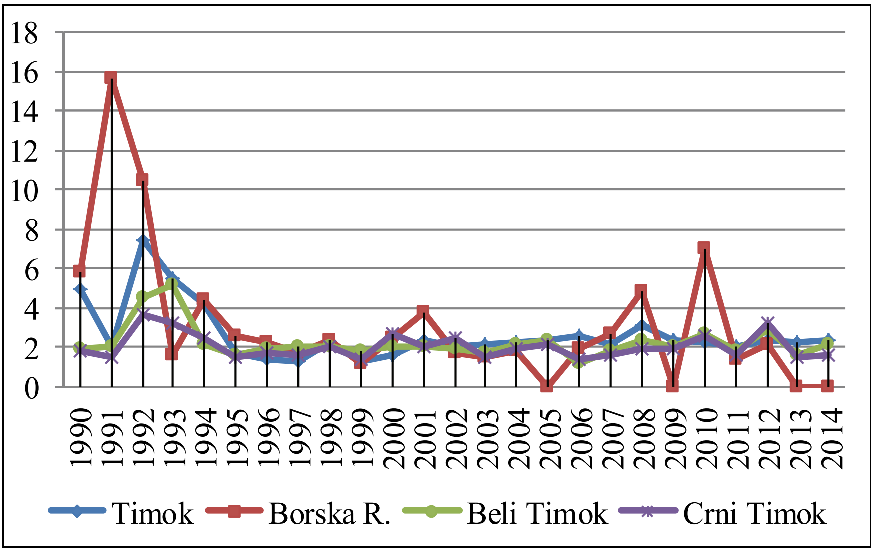

Figure 3: Annual average BOD5 values (mg/l) between 1990 and 2014

The measured values of the ammonium ion concentration were often above the admissible level, which indicates the pollution from industrial facilities and agricultural sources. The ammonium ion represents an important element in water quality evaluation (Hernea & Teche-Constantinescu, 2013). The highest values were recorded in the Borska Reka, where the maximum annual average value in 2004 was 11.2 mg/l.

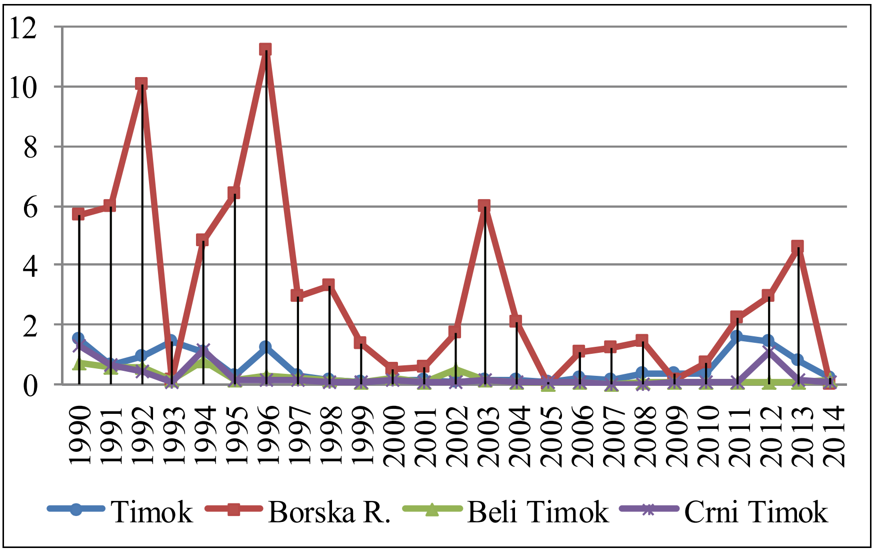

Figure 4: Annual average values of the ammonium ion concentration (mg/l) between 1990 and 2014

Correlation analysis of parameters dependence and SWQI for the same time period is given in the Table 2. The aim of correlation analysis is to indicate the existence of relations between the analyzed entities. The results obtained by correlation analysis and presented in the Table 2, show that there is no correlation between the measured parameters and calculated SWQI value. The only significant correlation exists between the parameter oxygen saturation and SWQI. This means that between the measuring points in time there are uncontrolled changes caused by different influences or what is more likely by different pollutants placed along the river Timok.

The application of the Water Quality Index method has enabled a comprehensive overview of the state of the surface water quality in the Timok River basin with a trend analysis and an interpretation of the obtained results using the descriptive quality indicators. Certain SWQI scores are the result of water quality changes caused by wastewater from human settlements and industrial facilities, agricultural sources and illegal waste disposal sites in the basin. In the period covered by the analysis, it was impossible to observe a trend of water quality improvement, which inevitably leads to the conclusion that pollution prevention measures were not taken.

Table 2: Correlation analysis of SWQI and calculation parameters for the Timok River*

	SO_2	BOD_5	NH_4^+	pH	WTN	PO_4	TSS	t	σ	FCB	SWQI
SO_2	1										
BOD_5	0.366	1									
NH_4^+	-0.89	-0.473	1								
pH	-0.628	-0.089	0.466	1							
WTN	-0.384	-0.565	0.746	0.155	1						
PO_4	-0.136	0.15	0.024	0.240	-0.179	1					
TSS	0.203	0.254	-0.326	0.5	-0.205	0.344	1				
t	-0.021	0.357	-0.078	-0.117	-0.159	-0.131	0.241	1			
σ	0.186	-0.149	0.07	-0.533	0.294	-0.546	-0.742	-0.169	1		
FCB	-0.119	0.103	-0.14	-0.01	-0.505	0.69	0.017	0.102	-0.178	1	
SWQI	0.807	0.058	-0.587	-0.789	-0.047	-0.607	-0.206	0.05	0.533	-0.445	1

Note: * oxygen saturation or SO_2, Five-Day Biochemical Oxygen Demand or BOD_5, ammonium ion concentration or NH_4^+, pH value, Water Total Nitrogen or WTN, Total Suspended Solids or TSS, orthophosphate concentration or PO_4, electrical conductivity or σ, temperature or t and the fecal coliform bacteria parameter or FCB

Conclusion

The obtained SWQI values indicate a high level of water pollution with organic and inorganic substances. The worst water quality was recorded in 1994, when the annual average SWQI for three rivers was in the “bad” range. It has been established that the annual average river flow trends also affected the SWQI values in the observed period.

The best water quality in the observed period was recorded in 2001. The SWQI value for the Borska Reka River remained in the “bad” range, whereas the water quality of other rivers fell into the “excellent” category. Untreated wastewater, agricultural waste and the waste from the Bor mining and industrial complex are the main source of pollution in the observed river basin.

The economy of the Timok River Basin rests upon the utilization of non-renewable resources through their exploitation, development of non-ferrous metallurgy and various manufacturing and processing facilities. Having in mind that these activities belong to the major sources of pollution, their development has resulted in a negative impact on the environment. The impact of mining and metallurgy on the quality and pollution of surface waters has been a subject of extensive research worldwide. This problem is partially covered in studies dealing with environmental changes caused by mining activities with a special focus on hydrologic changes (Schrek, 1998; Rigina, 2002; Razo, Carrizales, Castro, Díaz-Barriga, & Monroy, 2004).

The business policies of industrial companies in the Timok River Basin are not based on a sustainable approach to resources and environmental care. The integration among economic, social and ecological policies is lacking. Natural resource management should be included in the official sustainable development strategy. A coordinated action by all stakeholders (national and local authorities, economic and non-governmental organizations, etc.), including the participation of citizens, could contribute to a change of attitudes to water and the preservation of non-polluted and revitalization of degraded watercourses in the Timok River Basin. The priority tasks concerning water protection in future include: the introduction of mining wastewater treatment technologies, construction of systems for the treatment of communal and industrial wastewater, revitalization of degraded watercourses and their banksides and the education of the local population on water conservation.

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