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A CASE STUDY OF THE CORRELATION CRITERIA OF SURFACE WATER INTENDED FOR WATER SUPPLY *

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Abstract. *This paper gives a comparative analysis of the criteria for surface water quality classification in accordance with the current law regulations in Serbia, by applying the Serbian Water Quality Index (SWQI) method and Directive 75/440/EEC. The incompatibility of quality classification parameters for surface waters intended for water supply purposes is shown in the example of the assessment of water quality in the Barje accumulation, made on the basis of a data set provided by the Hydro-meteorological service of the Republic of Serbia for the years 2005-2009. Serbia's preparations for the EU integration processes include familiarization with European directives in the water sector, and the harmonization of the national legislation in this sector. The integral management of water resources sets new goals and standards for the solution of the problems in water supply, taking into consideration the real possibilities, basic principles, and requirements defined in the Water Framework Directive of the European Union.*

Key words: *Barje reservoir, DIRECTIVE 75/440/EEC, Serbian Water Quality Index*

INTRODUCTION

Drinking water has no alternatives; therefore, it is imperative to cleverly manage the available water resources and monitor the quality of surface water, which is used as a raw material for drinking water production. The accumulation lake Barje, with the total raw water volume of $41x10^6$ m^3, was designed to meet the current and future water supply requirements for the city of Leskovac. The identification of raw water quality features in the accumulation lake Barje is a pre-requirement for the adoption of an optimal procedure for drinking water purification which would meet quality standards, at the Gorina-

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Leskovac plant (Water Purification Facility Gorina - Leskovac). The descriptive water quality indicator and the calculated WQI and SWQI number define the state of the surface water and realistically assess the sustainability of its exploitation for drinking water production (Takić et al., 2010). Water quality monitoring is an important component of lake stewardship activities (Saskatchewan Watershed Authority Water Quality Guide, 2007). Comparison and compliance of current Serbian legislation with the acknowledged European surface water quality standards is a necessity for any improvement in water supply.

LEGAL FRAMEWORK FOR WATER QUALITY CONTROL IN SERBIA

In Serbian legislation, surface water quality control implies the enforcement of the Regulation on Watercourse Categorization and the Regulation on Water Classification in Serbia. All watercourses are classified into four categories and the required classes of water quality are defined at given watercourse segments. Surface water is then categorized, based on the threshold values of quality indicators, into class I, IIa, IIb, III, IV, and NC (not classified). Categorization is done based on the following indicators: suspended solids, total dry residue, pH, dissolved oxygen, BOD_5, degree of saprobity according to Liebman, degree of biological productivity, maximum number of coliform bacteria, visible waste matter, noticeable color, and noticeable odor (Regulation, Official gazette of the SRS, No. 5/68).

This Regulation does not provide a procedure for determining a mutual class to be compared with the prescribed one, based on eleven individually categorized quality indicators. Further improvement in legislation led to the Regulation on Classification of Water from Inter-republic Watercourses, Interstate Waters, and Yugoslav Coastal Waters which also categorized watercourses into four categories. Qualitative categorization was expanded by the addition of new indicators: oxygen saturation % O_2, COD, toxic matter, and radioactivity. Nevertheless, as in the previous Regulation, there was no procedure for determining a summary quality class based on the class of each quality indicator (Regulation, Official Gazette of the SFRJ, No. 6/78).

Table 1. Classification of surface water according to the Regulations in Serbia

Parameter (unit)	Water Class				
	I	II	III	IV	NC
Color	-	-	Little discernible	-	Discernible
Odor	-	-	Little discernible	-	Discernible
Visible waste matter	-	-	without	without	with
pH	6.8-8.5	6.8-8.5	6.0-9.0	6.0-9.0	< 6.0 / > 9.0
Dissolved oxygen (mg/l)	≥ 8	8-6	6-4	4-3	< 3
Oxygen saturation (%)	90-100	75-90	50-75	30-50	< 30
HPK, (mg/l)	≤ 10	10-12	12-20	20-40	> 40
NH_4N, (mg/l)	< 1	< 1	1-10	1-10	> 10
NO_2N, (mg/l)	< 0.05	< 0.05	0.05-0.5	0.05-0.5	> 0.5
Fenol,(μg/l)	1	1	300	300	> 300
Conductivity (μS/cm)	-	-	-	-	-

Class I surface water in its natural state and with possible disinfection is used for drinking, food manufacture, and for edible fish farming. Natural class II water is used for bathing and recreation, water sports, farming of certain fish species, and after it has been processed by conventional means (coagulation, filtration, disinfection, etc.), it can be used for drinking and food manufacture. Class III water is used for agriculture and, after standard processing, in industry, with the exception of the food industry. Class IV water can be used only after it has been properly processed, whereas NC represents an unclassified state (Regulation, Official Gazette of the SFRJ, No. 33/87).

The law does not define precisely the procedure for the final assessment of a summary class of watercourse quality, which opens the possibility of numerous arbitrary assessments.

WATER QUALITY BY USE OF SWQI METHOD AND DIRECTIVE 75/440/EEC

Surface waters are complex multi-component systems the study of which depends on the knowledge and application of facts, principles, and methods from chemistry, physics, geology, hydrology, meteorology, mathematics, and other sciences with the purpose of solving essentially ecological problems. The particularity and complexity of surface water chemical composition and of quality indicators (representing the effects of various dissolved substances such as mineral and organic matter, gases, colloids, suspended particles, and microorganisms, present in water through natural or artificial processes) stress the importance of applying quality index methods for their assessment by identifying a common factor which encompasses quality as a whole.

Investment in improving the quality of surface water requires the monitoring and evaluation of water quality (Newsome and Stephen, 1999).

The Agency for Environmental Protection has developed an indicator of the environment for the area of water that is intended for reporting to the public, experts and decision makers (local government, state agencies). The indicator is based on the method of *Water Quality Index* (Scottish Development Department, Engineering Division, Edinburgh, 1976) according to which the ten parameters of physical-chemical and microbiological quality of aggregate in the composite indicate surface water quality.

The method of *Water Quality Index* (WQI) of ten selected parameters (oxygen saturation, BOD5, ammonium ions, *pH* value, total nitrogen, orthophosphate, suspended matter, temperature, electrical conductivity and coliform bacteria) have the quality *(q and)* and represent the characteristics of surface waters by reducing them to an index number. The share of each of the ten parameters in the overall water quality has the same relative importance, because each of them won their weight *(w and)* and the number of points to share in jeopardizing quality. Summing up the product *(q and xw and)* gets the index of 100 as the ideal sum of share the quality of all the parameters. In the case of missing data on the quality of a parameter value, the measured arithmetic *WQI* wascorrected by multiplying the index with a value of $1 / x$, where x is the arithmetic sum of the measured weight of the available parameters (http://www.water-research.net/watrqualindex/index.htm).

Indicators of surface water quality using the *Serbian Water Quality Index* was obtained by a comparison of quality indicators according to the Serbian classification and the original method of *WQI* (Table 2) (Official Gazette of the SFRJ, No. 6/78).

Table 2. A comparison of the quality indicators according to the Serbian classification and methods of *WQI*

Serbian Water Quality Index					
Parameters (unit)	Max. value. q and x w and	MAC I class	MAC II class	MAC III class	MAC IV class
Oxygen saturation (%)	18	90-105 -	75-90 105-115	50-75 115-125	30-50 125-130
BOD5 (mg/l)	15	2	4	7	20
Ammonium (mg/l)	12	0.1	0.1	0.5	0.5
pH value	9	6.8-8.5	6.8-8.5	6-9	6-9
Total oxides of nitrogen (mg/l)	8	10.05	10.05	15.5	15.5
Orthophosphates (mg/l)	8	0.005	0.01	0.01	0.01
Suspended solid (mg/l)	7	10	30	80	100
Temperature (^{o} C)	5	-	-	-	-
Conductivity (μS/cm)	6	-	-	-	-
E. Coli (MPN in 1000 ml)	12	2.000	100.000	200.000	200.000
Σ (q and xw and) = WQI	100	85-84	69-71 74-71	44-48 56-52	35-36 51-46

The quality of the surface water that corresponds with the *and* to the Serbian Regulation by *WQI* belongs to 84-85 points, *II* class to 72-78 points, *III* class to 48-63 points, and *IV* class to 37-38 points. The adopted values of descriptive indicators of the quality *WQI* = 0-38 is very poor, *WQI* = 39-71 bad, *WQI* = 72-83 good, *WQI* = 84-89 very good and *WQI* = 90-100 excellent (Agency for Environmental Protection).

The classification system of surface water quality according to the Serbian Water Quality Index (SWQI) method represents a method for the evaluation of the quality of a group of selected parameters, which means that by the implementation of this method, the overall evaluation of the surface water quality can be obtained.

SWQI indicators of surface water quality were obtained by comparing the quality parameters according to our classification with those of the original *WQ*I method. The adopted descriptive classification criteria of the descriptive quality indicators and the determination of the surface water class according to the calculated SWQI value are given in Table 3.

Table 3. The classification of surface waters according to the Water Quality Index method

WQI - (Class I)		WQI - Class II	WQI - Class III	WQI - Class IV
85 - 84		74 - 69	56 - 44	51 - 35
100 - 90	89 - 84	83 -72	71 - 39	38-0
Excellent	Very good	Good	Bad	Very bad
Serbian Water Quality Index (SWQI)				

Indicators of the quality of surface waters are classified in terms of compatibility with the existing classification according to their purpose and degree of purity:

- Excellent – water that is the natural state of the filtration and disinfection, can be used to supply water to settlements in the food industry, and surface water and the cultivation of precious fish species;
- Very good and good – the water in its natural state can be used for swimming and recreation of citizens for water, for breeding of other fish species (cyprinids), or that the modern methods of treatment can be used to supply drinking water to villages and the food industry;
- Poor – water that can be used for irrigation, and after the modern methods of treatment and in industry, except food;
- Very poor – have the quality of water that adversely affect the environment, and can only be used after the use of special methods of treatment (Agency for Environmental Protection).

The WQI index numerically summarizes the information from multiple water quality parameters into a single value. Assessment of surface water quality using the WQI method is presented in many papers so that a large number cannot be mentioned (Banerjee and Srivastava, 2009, Tirthanker, 2009, Region, 2010, and many others). An interesting study is the development of the WQI method and proposes the introduction of the Universal water Quality Index (UWQI) based on a European classification scheme (Boyacioglu, 2007).

The water policy in the European Union is based on the principle of self-sustainable development of water systems through the application of the Water Framework Directive (WFD) (Environment Agency). The key principle of the EU Water Framework Directive is expressed by the statement that water is not a commercial product but an heritance that should be guarded, protected, and accordingly treated. The familiarity with this Directive is important as a starting point in our country's preparations for the EU integration processes from the aspect of the present international cooperation in the water system. As regards the legal framework of the surface water quality control from the aspect of its suitability for water supply, our Regulation is comparable to the *Council Directive 75/440/EEC*, which refers to the required quality of surface water intended for human consumption in Member States (European Council Drinking Water Abstraction Directive).

According to this Directive, surface waters are categorized into three classes with respect to the values of the quality parameters:

A1 – Simple physical treatment and disinfection, e,g. Rapid filtration and disinfection;
A2 – Normal physical treatment, chemical treatment and disinfection, e.g. pre-chlorination, coagulation, flocculation, decantation, filtration, disinfection, final chlorination;
A3 – Intensive physical and chemical treatment, extended treatment and disinfection, e.g. chlorination to the breaking -point, coagulation, flocculation, decantation, filtration, adsorption (activated carbon), disinfection (ozone, final chlorination);

This classification is based on the assessment of about 45 water quality parameters including physical, chemical and microbiological variables such as temperature, pH, colour, sodium, biochemical oxygen demand, mercury, lead, iron and total coliform, etc. Each class is characterised by numerical values for these parameters.

These classes correspond to three different surface water qualities according to their physical, chemical, and microbiological characteristics presented in the table in Annex II. Surface water having physical, chemical and microbiological characteristics falling short of the mandatory limiting values corresponding to treatment type A3 may not be used for the abstraction of drinking water. However, such lower quality water may, in exceptional circumstances, be utilized, provided suitable processes are used to bring the quality characteristics of the water up to the level of the quality standards for drinking water (European Council Drinking Water Abstraction Directive).

Table 4. The correlation between Method WQI and DIRECTIVE 75/440/EEC

Parametar (unit)	WQI_{max} qixwi	A1	WQI_A qix wi	A2	WQI_{A2} qixwi	A3	WQI_A qix wi
Oxygen Saturation (%)	18	>70	11	>50	6	>30	2
BOD_5 (mg/l)	15	<3	11	<5	7	<7	4
Ammonium jon (mg/l/N)	12	0.05	12	1	3	2	2
pH	9	6.5-8.5	9-7	5.5-9	5	5.5-9	5
Total Oxidased Nitrogen (mg/lN)	8	1	7	2	6	3	5
Ortofosfate (mg/lP)	8	0.4	4	0.7	1	0.7	1
Suspended solid (mg/l)	7	25	4	25	4	25	4
Temperature (°C)	5	22	2	22	2	22	2
Conductivity (μS/cm)	6	1000	0	1000	0	1000	0
E.Coli (MPN/100ml)	12	20	12	2000	10	20000	7
qixwi=WQI	100				44		32

The comparison of the two classification tables 3 and 4 shows that:

- The quality of surface water corresponding to Class I according to our Regulation assessed by WQI method matches 84-85 index points, Class II 72-78 index points, Class III 71-39 index points, and Class IV 38-0 index points.
- The quality of the surface water corresponding to Class I according to our Regulation assessed by SWQI method matches 84-100 index points, Class II 83-72 index points, Class III 71-39 index points, and Class IV 38-0 index points.
- The quality of surface water corresponding to Category A1 of the Directive 75/440/EEC assessed by the WQI method matches 70-100 index points, A2 44-72 points, and Category A3 0-32 index points.

A COMPARATIVE ANALYSIS OF WATER QUALITY IN THE ACCUMULATION LAKE BARJE

The Hydro-meteorological service of the Republic of Serbia performs systematic monitoring of quantitative and qualitative characteristics of surface and groundwater in order to determine, analyze, and monitor the water regime on the territory of Serbia according to the Law on Waterways, and in conformance with the Regulation on systematic water quality control passed by the Government of Serbia. Continuous monitoring of the regime, together with the simultaneous determination of the quantity and quality of water, provide a relevant source of technical information for the presentation of the state of water resources in real time, as a basis for action in the water management field, protection

from the destructive effects of water, the protection of waters from pollution, and optimal utilization of water. The result of the introduction of the water quantity and quality monitoring is a significant amount of data collected in the Hydrology information system base, to be published in form of a hydrology almanac.

In accordance with the hydro-meteorological service program, the testing of the water quality from the accumulation is carried out on three locations: at the dam, in the middle of the lake, and at the beginning of the lake. The sampling of the water from the Barje accumulation lake was performed at three depths (surface, mid-depth and bottom): d_1 = 0.5 m, d_2 = 15 m, d_3 = 28 m; d_1 = 0.5 m, d_2 = 8 m, d_3 = 15 m, and d_1 = 0.5 m, d_2 = 1 m, d_3 = 1.5 m, respectively, at the given lake locations. For the purpose of this investigation for the period 2005-2009, the averaging of individual parameters of the water quality was done as instructed by *Eurowaternet – Lakes Aggregation of station data* (European Environment Agency), and the calculated value expressed by the corresponding SWQI index number (Table 5).

Table 5. SWQI quality of water in the accumulation lake Barje for the years 2005-2009

Parametar (unit)	2005	2006	2007	2008	2009
Temperature (^{o} C)	13.4	13.5	14.4	14	14.2
pH	8.1	8.0	7.9	8.0	8.1
Suspended solid (mg/l)	392.8	439.7	395.4	401.0	394.1
Conductivity (μS/cm)	92.1	97.2	93.9	92.8	95.8
Ammonium jon (mg/l/N)	2.6	2.8	2.5	2.6	2.3
Total Oxidased Nitrogen (mg/lN)	34.7	25.9	24.5	28.9	23.1
Ortofosfate (mg/lP)	1.569	1.662	1.384	1.391	1.326
Oxygen Saturation (%)	0.054	0.093	0.089	0.066	0.080
BOD_5 (mg/l)	0.17	0.17	0.10	0.11	0.10
E.Coli (MPN/100ml)	6888	9918	5972	4629	6957
SQWI	79	79	83	81	85

The quality of water from the Barje accumulation lake corresponds to the characteristics of Class I and II according to the SWQI classification and meets the required quality for the surface waters intended for human consumption. The regularity of the water quality change in the Barje accumulation is obtained by analyzing the SWQI index values in the investigated 2005-2009 period. The variations of time series are graphically presented by a trend line that should average the existing changes of SWQI values of the time series and present the average, and to show the tendency of water quality changes over a longer period of time.

Figure 1 shows an empirical time series of SWQI values with an approximately linear tendency, so that it is best presented by a linear fit with an average quality trend of 84.2 and absolute fall by an average -1.9 SWQI index points of the quality of water from the Barje accumulation lake for each year in the analyzed period.

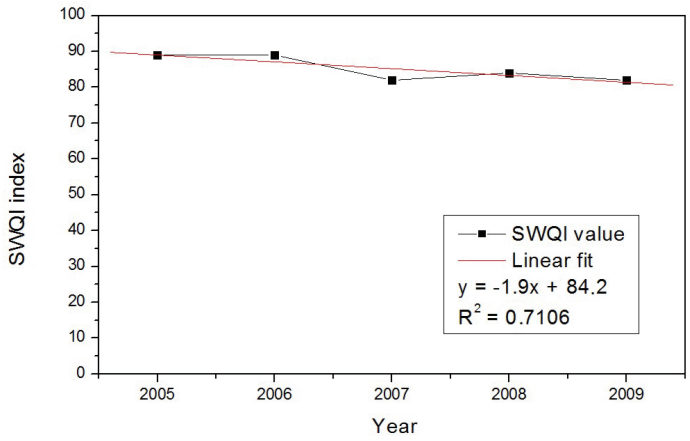

Fig. 1. The linear trend of quality variation the water of the accumulation lake Barje given in SWQI values

According to the current Regulation on classification, the water belongs to the class marked by the most unfavorable parameter of water quality. That means that, if a single parameter exceeds the allowed concentration of an individual class and is classified in a lower class, the water quality follows it to that lower class. Thus, according to the results of the physical and chemical analyses of the samples presented in the Hydrology Almanac for the period 2005-2009, there were instances of increased pH values and dissolved oxygen values on the location at the dam on three different sampling depths corresponding to Class III of the water quality. The occurrences of exceeding of individual parameters of water quality classify the water as belonging to a lower class, which is not a real indicator of the water quality.

By applying the current Regulation on water classification, the water from the Barje accumulation was classified as Class I and Class II quality, which is partly in concordance with the number of index points by the SWQI method, but it is not a valid indicator of the real state of water quality. The criterion of Class I water quality of the Barje accumulation lake, in view of its suitability for human consumption, should correspond to SWQI = 84-100 index points.

By applying the correlation classification criteria based on the average number of index points SWQI = 84.2 it can be seen that the water quality of the Barje accumulation lake corresponds to Class I according to the current national regulations, i.e. to Category A1 according to Directive 75/440/EEC regarding the quality of surface water intended for water supply.

Generally, the analysis shows that, regardless of parameter incompatibility, the water quality from the Barje accumulation lake is controlled by the aforementioned methods meets the required quality of surface water intended for human consumption.

CONCLUSIONS

Water quality is one of the most important characteristics of any accumulation, which must be taken care of during all the stages of planning and using a water resource system. The most significant measures of the water resources protection are water monitoring, categorization and determination of water quality standards. The water from the Barje accumulation meets the criterion for water intended for human consumption. Comparison and harmonization of current nation legislative regulations with suggested European methods for the determination of surface water quality indices is an imperative for the improvement of water supply.

The fact that the Republic of Serbia has applied for the integration into the European Union makes it necessary to harmonize the national legislation in the water sector with European directives. Integral management of water resources sets new goals and standards for problem solving in a water supply system, taking into consideration real possibilities and basic principles and requirements defined in the EU Water Framework Directive.

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STUDIJA SLUČAJA KORELACIONIH KRITERIJUMA POVRŠINSKIH VODA NAMENJENIH ZA SNABDEVANJE PIJAĆOM VODOM

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U radu je prikazana komparativna analiza kriterijuma klasifikacije kvaliteta površinskih voda prema aktuelnoj nacionalnoj zakonskoj regulativi, primenom metode Serbian Water Quality Index (SWQI) i Direktive 75/440/EEC. Na primeru proračuna kvaliteta vode akumulacije Barje, polazeći od fonda podataka RHMZ Srbije objavljenih u Hidrološkim godišnjacima za period 2005-2009. godina, pokazana je nekompatibilnost parametara klasifikacije kvaliteta površinskih voda namenjenih vodosnabdevanju. Priprema naše zemlje u integracione procese EU podrazumeva upoznavanje i harmonizaciju nacionalnog zakonodavstva u sektoru voda sa Evropskim direktivama. Integralno upravljanje vodnim resursima postavlja nove ciljeve i standarde rešavanja problema u vodoprivredi uvažavajući realne mogučnosti, osnovne principe i zahteve definisane Okvirnom direktivom o vodama Evropske Unije.

Ključne reči: *Srpski indeks kvaliteta voda, Direktiva 75/440/EEC, Akumulacija Barje*