

## THE ASSESSMENT OF THE DANUBE WATER QUALITY IN SERBIA

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This paper considers the assessment of the Danube water quality in accordance with the current law regulations in Serbia by applying the Serbian Water Quality Index (SWQI) method and Directive 75/440/EEC. Monitoring of the surface water quality is performed by the Republic Hydrometeorological Service of Serbia (RHSS) so data found in the period from 2005 to 2009 are used. Comparative analysis shows the incompatibility of classification parameters of the Danube water quality. Also, the knowledge of these regulations provides a better and more reliable monitoring of the surface water quality. The paper aims to show the preparations of Serbia for the European Union (EU) integration processes along with the challenges and difficulties in the process of implementation of EU Water Framework Directive (WFD).

**Keywords:** the Danube, SWQI, Directive 75/440/EEC.

### Introduction

The poor quality of the surface water is still a significant problem in many parts of the world. It can often limit the use of this vital resource and, in more extreme cases, harm human and other lives. Monitoring involves biological as well as chemical and physical measurements of the quality that can be expressed in a form of the quality index. Periodic assessments of the general quality on a national or international basis are also used to monitor the overall progress [1].

Continuous monitoring of the régime, together with the determination of the water quantity and quality, provides a relevant source of information in presenting the state of water resources in real time. The analysis of the quality of the surface water is fundamental for a sustainable management of water resources.

The Danube is Europe's second largest river, 2857 km long, with a drainage area of almost 801,500 square kilometers. It originates in the Black Forest in Germany and passes through Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Romania, Bulgaria, Moldova, and Ukraine. The European Commission recognizes the Danube as the "single most important non-oceanic body of water in Europe" and as a "future central axis for the European Union". About 588 km of total Danube's length flows through

Serbia. Its largest tributaries on the territory of Serbia are the Tisza, the Tamiš and the Danube-Tisza-Danube canal on the left, and the Drava, the Sava and the Velika Morava on the right side [2].

The European Union (EU) has defined its long-term policy in the water domain when the European Parliament and the European Council passed EU/WFD-2000/60/EC Water Framework Directive on October 23, 2000. Water Framework Directive (WFD) is the most important legal instrument in the area of water and a precondition for a successful realization of the concept of integral environmental management. Specific conditions regarding the implementation of the adopted policy of the sustainable use and protection of water are formulated in the Directive. The fundamental aim of the WFD is to bring all natural water into "good condition", i.e. to ensure a good hydrological, chemical and ecological status of the water [3].

The familiarity with this Directive is important to Serbia in preparations for the EU integration processes from the aspect of the present international cooperation in the water system. The future quality assessment should be based on the evaluated risks made considering both the experience of developed countries and local conditions [4].

Having in mind that the Danube water is one of the most

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valuable natural water resources in Serbia, a special attention must be paid to its evaluation, pollution and protection problems. The RHSS [5] undertakes systematic monitoring of quantitative and qualitative characteristics of the surface and ground water in order to determine, analyze and supervise the water régime on the territory of Serbia under the Waters Act and in compliance with the Regulation of the Systematic Waters Quality Testing passed by the Government of the Republic of Serbia. The scope, type and frequency of the waterways quality control in the Republic of Serbia are stipulated by the Program of Water Quality Testing. According to the accepted methodology, the basic physico-chemical parameters are tested once a month. The additional physico-chemical parameters are determined at least four times a year, while metals and other harmful and dangerous substances are checked three to twelve times a year, depending on the economic importance of the given waterway. Total radioactivity is measured two to seven times a year in all more important profiles. The results of the established monitoring of the water quantity and quality are reflected in a significant number of data collected in the Hydrological Information System [5].

The scope of this research is a comparative analysis of the Danube water quality on its course through Serbia using current available data of the RHSS [5] for the period of time from 2005 to 2009.

### Legal framework for the water quality control in Serbia

In Serbian legislation, the quality control of the surface water implies the enforcement of the Regulation on Watercourse Categorization and the Regulation on Water Classification in Serbia [6]. All watercourses are classified into four categories and the required classes of the water quality are defined at given watercourse segments. Surface water is then categorized, based on threshold values of quality indicators into classes I, IIa, IIb, III, IV, and NC (not classified). The categorization is done based on the following indicators: suspended matter, total dry residue, pH, dissolved oxygen, biochemical oxygen demand (BOD-5), a degree of saprobity according to Liebmann, a degree of biological productivity, maximum number of coliform bacteria (*E. coli*), the visible waste matter, noticeable color, and noticeable odor [6].

This Regulation does not provide a procedure for determining the actual class to be compared with the required one, based on the eleven individually categorized quality indicators. Further improvement of 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 [7, 8]. The qualitative categorization was expanded by the addition of new indicators: oxygen saturation, chemical oxygen demand (COD), toxic matter, and radioactivity [9].

Nevertheless, as in the previous Regulation there was no procedure for determining a summary quality class

based on the class of each quality indicator. Class I surface water represents the water in its natural state that can be used for drinking, in food industry or for fish breeding. Natural class II water is used for swimming and recreation, water sports, breeding of certain fish species and, after being processed with conventional methods (coagulation, filtration, disinfection, etc.), it can be used for drinking or in food industry. Class III water is used for agriculture and, after standard processing, in industry, with the exception of food industry. Class IV water can be used only after being properly processed whereas NC represents the unclassified state [8, 10].

The implementation of the new by-law [11] implies the ecological status, ecological potential and chemical status of surface waters determined by the parameters classified in the following quality elements: 1) biological, 2) chemical and physico-chemical that are important for biological elements for a given category of the surface water and given type of the water body of the surface water, 3) hydromorphological elements of importance for biological elements for a given category of the surface water and a given type of the water body of the surface water.

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

### Water Quality Index (WQI)

The study of the surface water as a complex multi-component system depends on the knowledge and application of facts, principles, and methods from chemistry, physics, geology, hydrology, meteorology, mathematics and other sciences for the purpose of solving the essential ecological problems. The particularity and complexity of the 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 mutual factor that includes quality as a whole [12].

Serbian Environmental Protection Agency [13] has developed an indicator of the environment for the area of the water intended for reporting to the public, experts and decision makers (local government, state agencies). The indicator is based on the method of WQI [14] according to which the ten parameters of physico-chemical and microbiological quality aggregate in the composite indicator of the surface water quality.

According to the method of WQI, ten selected parameters (oxygen saturation, *E. coli*, BOD-5, pH value, total nitrogen oxides, orthophosphates, suspended matter, ammonium, temperature and conductivity) aggregate in the composite indicator of the surface water quality. These parameters have the quality ( $q_i$ ). The share of each of the ten parameters in the overall water quality does not have the

same relative importance, so they each got their weight ( $w_i$ ) and points according to the share of jeopardizing the quality. Summing the products ( $q_i \times w_i$ ) the index of 100 is obtained as ideal total weight for all parameters. Depending on the number of points of individual parameters, the given water will be allocated a number of index points ranging from 0 to 100. In the case of missing data for an individual parameter, the value of arithmetically determined WQI is adjusted by multiplying the index value with  $1/x$ , where  $x$  is the sum of arithmetically measured weights of available parameters [13].

WQI numerically summarizes the information from multiple water quality parameters into a single value [15]. The determination of the water quality using a single index number is a simpler approach than comparing the measured individual indicators of the water quality parameters with the reference values [16]. The assessment of the surface water quality using WQI method has been widely studied [17-20]. The descriptive water quality indicator and the calculated WQI numbers define the state of surface water and realistically assess sustainability of its exploitation for the drinking water production [21].

WQI is used to estimate the cleanness of the water. It contains the lists of basic and additional parameters, a formula for the summarized index and the algorithm for the evaluation of a summarized and guaranteed index. It is illustrated by practical examples of WQI evaluation in the rivers of the Vistula basin in Poland [22]. In Taiwan, WQI was developed as the river water quality index. It is a multiplicative aggregate function of standardized scores for temperature, pH, toxic substances, organics (dissolved oxygen, BOD-5, ammonia), particulate (suspended matter, turbidity) and microorganisms such as faecal coliforms [23]. Water pollution, as a consequence of rapid industrial growth has raised concern for public health and the environment. The application of the water quality index for the evaluation of surface water in order to estimate the degree of influence on the environment is giving excellent results [17].

### Serbian Water Quality Index (SWQI)

The classification system of the surface water quality description according to the SWQI method represents a method for the evaluation of quality for a group of selected parameters, which means that by implementing this method an overall evaluation of the surface water quality can be obtained [24].

SWQI indicators of the surface water quality were determined by comparing the quality parameters of Serbian classification with those of the original WQI method. The indicators of the quality of the surface water are classified in compatibility with the existing classification according to their purpose and degree of purity:

- Excellent – the water in its natural state that can be used to supply settlements with water, as well as in food industry (by using filtration and disinfection methods), while as a surface water it can be used for breeding pre-

vious fish species;

- Very good and good – the water in its natural state that can be used for swimming and recreation, water sports, for breeding of other fish species or, by using modern purification methods, for water supply systems and in food industry;

- Bad – the water that can be used for irrigation and, after being treated with modern methods, for industries other than food industry;

- Very bad – the waters that have an adverse effect on the environment and can only be used after special treatment (purification) methods [13].

### Water quality and Directive 75/440/EEC

Council Directive (Directive 75/440/EEC) of 16 June 1975 [25] concerning the required quality of the surface water intended for the abstraction of drinking water in the Member States is a correlated regulation to the legal framework for the surface water quality control from the aspect of its suitability for the drinking water supply in Serbia and it refers to the required quality of the surface water intended for drinking water abstraction in Member States. According to this Directive [25], the surface water is categorized into three classes with respect to the limit values of the quality parameters:

A1 – Simple physical treatment and disinfection;

A2 – Normal physical treatment, chemical treatment and disinfection;

A3 – Intensive physical and chemical treatment, extended treatment and disinfection.

This classification is based on the assessment of about 45 water quality parameters including physical, chemical and microbiological variables such as temperature, pH, color, sodium, BOD-5, mercury, lead, iron, *E. coli*, etc. Each class is characterized by numerical values for these parameters according to Annex II of the Directive 75/440EEC [25, 26].

The correlation of the criteria for the surface water quality classification in accordance with the current law regulations in Serbia, by applying the WQI, SWQI and Directive 75/440/EEC shows that:

- The quality of the surface water corresponding to Class I according to our Regulation assessed by SWQI method matches 100-84 index points, Class II matches 83-72 index points, Class III matches 71-39 index points and Class IV matches 38-0 index points;

- The quality of the surface water corresponding to Category A1 of the Directive 75/440/EEC assessed by WQI method matches 100-70 index points, A2 matches 69-44 points and Category A3 matches 43-0 index points.

### Comparative analysis of the Danube water quality

The Danube, as the most important river in Europe, is the subject of numerous investigations of various aspects. Our results are reflective of other results reported in literature. For instance, Milanović et al. [27] point out that

there is a significant problem concerning the required water quality and it is one of major obstacles in the economic development of Serbia along the Danube banks. The results showed that with respect to the percentage of oxygen saturation, the Danube water quality at the point of entry in Serbia (at Bezdán) was not classified (NC), while with respect to other parameters it corresponded to class III/IV of the water quality. A contribution to the better water quality is the construction of the Đerdap accumulation which acts as a huge precipitator. The Regulation on water classification stipulates that the water should be classified into the category of the most unfavorable parameter, so that present excessive values of individual parameters of the Danube water on the territory of Serbia categorize it as Class III water quality for the observed period from 2001 to 2008 [27].

Also, the analysis of the long-term changes of selected eco-chemical parameters and the determination of differences in comparison to the natural variability reveal a steady improvement of the parameters and acceptable trends in the eco-chemical status of the Danube, as well as readily discernible differences in the water quality between the entry and exit points of the Danube in Serbia [28, 29].

Based on the result analysis of the RHSS [5] for the year 2009, it can be ascertained that the water quality of the Danube, at all control points, did not meet the requirements of the Class II water quality. More specifically, along the course of this recipient between Bezdán and Slankamen, there is a characteristic occurrence of oxygen supersaturation (Class III and NC status), as well as increased values of BOD-5 (III) in some measurements made at Bezdán, Apatin and Slankamen profiles. At this part of the course, pH value of the water ranged from 7.8 to 8.7 so that periodically it corresponded to Class III water quality. The values for suspended matter varied and often remained within the Class III water quality limits. As regards harmful and dangerous substances, the increased values of phenol index (III/IV) were measured at profiles Beograd-Vinča, Smederevo and Banatska Palanka. Periodically, the increased concentrations of iron (Fe) were recorded at these profiles and, only at Bačka Palanka, in a single measurement, an increased concentration of manganese (Mn), copper (Cu) (NC status) and zinc (Zn) (III/IV) was recorded.

At Bogojevo profile, in a single case, higher concentrations of chrome (Cr), copper (Cu) (NC status) and zinc (Zn) (III/IV and NC status) were recorded. In the area of Zemun-Radujevac, during sampling, a change of organoleptic indicator was observed, i.e., the color of the water at Dobra and Tekija corresponded in one series to Class III water quality. In certain series of measurements at profiles Veliko Gradište, Dobra, Tekija, Brza Palanka and Radujevac, the percentage of oxygen saturation belonged to Class IV quality and NC status. Higher BOD-5 values and suspended matter at profiles Zemun and Pančevo corresponded periodically to Class III water quality. Higher values of petrol hydrocarbons (III/IV) were recorded in one

measurement at profile Radujevac. Saprobiotic testing of the River Danube water quality, at monitored profiles, indicates the presence of moderate organic pollution. Bio-indicators of  $\beta$  and  $\alpha$ -mesosaprobic zone prevail in the waterway. In all investigation periods the dominance of silica algae is characteristic, while in the summer period a significant presence of green algae is observed. According to the categorization, the obtained values of saprobity index correspond to Class II water quality. The deviation from Class II was only present in one measurement at Brza Palanka profile in autumn, when an increased organic pollution was observed and the water quality corresponded to Class II/III [5].

The focus on the individual water quality indicators shows that the water class may differ, which implies that a summarized assessment of the water quality based on the total effect of all indicators was not conducted. Current exceeding of certain water quality parameters classifies water into a lower class, which is not a real indicator of the water quality. The available data show a great disproportion between the law required and the actual state of the Danube River water quality.

The basic principles contained in the Directive will be applied not only in the EU Member States but also in candidate countries. Obviously, this document will be the base for making specific plans for water resources management within the international river basins in Europe. This means that Serbia has to initiate the harmonization of national laws, regulations, standards and institutes in the water and the environment domain with those already in force in the European Union [3].

A comparative analysis of the Danube water quality on its course through Serbia starts from the Data Fund of the RHSS [5] for the period from 2005 to 2009. The investigation of the Danube water quality for the year 2009 includes sixteen hydrological measuring stations presented in Table 1. The selected parameters show physical, chemical and microbiological characteristics of the water and all together they give a summary of the Danube water quality by calculated SWQI values.

Based on the above, it can be concluded that according to the legislation and by applying the Regulation [6], the water quality of the Danube on its course through Serbia was classified as Class II and III for the year 2009, which is to some extent a satisfactory degree of compliance with the number of index points determined by SWQI method at individual profiles, but not the real indicator of the Danube water quality status.

A map of profiles, where the Danube water analysis was performed, together with sixteen measuring points with calculated SWQI values for the investigated period are presented in Figure 1.



**Table 1.** The Danube water quality at 16 measuring stations for the year of 2009

	1 Bezdán	2 Apatin	3 Bogojevo	4 Bačka Palanka	5 Novi Sad	6 Slankamen	7 Čenta	8 Zemun	9 Pančevo	10 Smederevo	11 Banatska Palanka	12 Veliko Gradište	13 Dobra	14 Tekija	15 Brza Palanka	16 Radujevac
Temperature (°C)	13.2	15.9	13.2	14.1	13.7	13.9	14.1	14.0	14.6	14.9	14.5	14.6	14.1	15.5	14.5	15.5
pH	8.3	8.4	8.3	8.2	8.3	8.3	8.3	7.8	8.2	7.8	7.9	7.7	7.9	7.8	7.8	7.7
Conductivity (µS cm <sup>-1</sup> )	411.8	401.7	411	401.3	398.5	393.3	393.5	392.9	398.3	381.6	379.9	377.7	370.0	369.6	370.6	372.6
Oxygen saturation (%)	97.7	100.9	100.3	92.5	96.0	97.5	98.6	94.2	95.7	96.7	88.7	91.3	101.4	93.6	94.8	93.2
BOD-5 (mg L <sup>-1</sup> )	2.2	2.5	2.3	2.0	2.5	2.3	2.2	3.1	2.3	2.6	1.5	1.7	1.7	1.8	1.5	1.9
Suspended matter (mg L <sup>-1</sup> )	32.4	27.1	31.9	24.9	23.3	25.8	20.5	21.8	31.6	17.3	28.8	13.2	10.8	8.8	9.3	9.8
Total Nitrogen oxides (mg L <sup>-1</sup> )	1.891	1.713	1.789	1.619	1.574	1.652	1.666	0.751	1.332	0.748	1.364	0.905	0.864	0.791	0.934	0.983
Orthophosphates (mg L <sup>-1</sup> )	0.044	0.046	0.038	0.040	0.047	0.04	0.041	0.073	0.047	0.061	0.049	0.058	0.054	0.044	0.056	0.200
Ammonium (mg L <sup>-1</sup> )	0.08	0.04	0.09	0.07	0.06	0.07	0.07	0.11	0.09	0.13	0.15	0.09	0.08	0.07	0.10	0.12
<i>E. coli</i> (u 100 ml)	11498	10300	11350	13900	1727	1200	/	2400	18525	2400	6848	7360	7050	12425	6230	636
<b>SWQI</b>	<b>82</b>	<b>82</b>	<b>82</b>	<b>82</b>	<b>84</b>	<b>85</b>	<b>85</b>	<b>83</b>	<b>81</b>	<b>85</b>	<b>86</b>	<b>87</b>	<b>90</b>	<b>90</b>	<b>90</b>	<b>88</b>
<b>SWQI average value</b>	<b>85</b>															

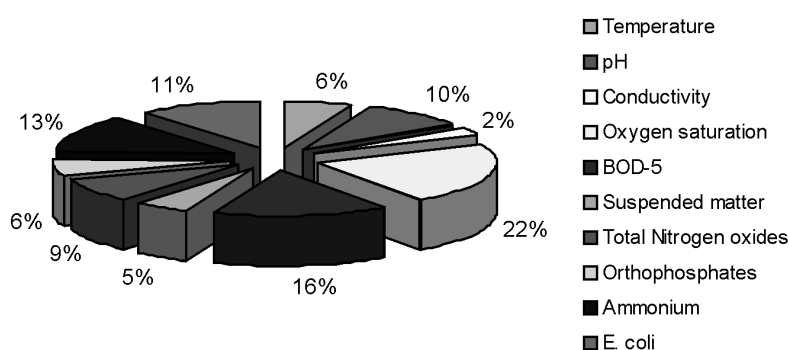


**Figure 1.** The map of profiles where the investigation of the Danube water quality was performed with SWQI values for the year 2009

The calculated SWQI value for each measuring point in 2009 shows that the Danube quality along its course was in the range from 82 to 90, which corresponds to descriptive indicators of "good", "very good" and "excellent" water. At the entry point (Bezdan profile) SWQI value was 82, and at the exit point (Radujevac) 88. The highest SWQI value (90) was calculated at profiles Dobra, Tekija and Brza Palanka, while the lowest index (81) was determined at the measuring section in Pančevo near Belgrade. An overall Danube water quality determined by a median of arranged series of average values amounts to SWQI = 85 for the monitored one-year period, and corresponds to Class I,

i.e. descriptive indicator "very good" water, and meets the required quality of the surface water.

The percentage value of each individual parameter (Figure 2) represents a quantitative share of individual parameters in average SWQI value for the year 2009. It can be concluded that the parameter with the most significant share is "Oxygen saturation" (22 %), followed by respectively "BOD-5" (16 %), ammonium (13 %), E. coli (11 %), pH (10 %), "Total Nitrogen oxides" (9 %), followed by "Orthophosphates" and "Temperature" (both with 6 % of share), "Suspended matter" (5 %) and "Conductivity" with the smallest proportion (2 %).



**Figure 2.** The share of parameters in SWQI value of the water quality

**Table 2.** The Danube water quality for the period from 2005 to 2009

Parameter (Unit)	2005	2006	2007	2008	2009
Temperature (°C)	13.4	13.5	14.4	14	14.2
pH	8.1	8.0	7.9	8.0	8.1
Conductivity ( $\mu\text{S cm}^{-1}$ )	392.8	439.7	395.4	401.0	394.1
Oxygen saturation (%)	92.1	97.2	93.9	92.8	95.8
BOD-5 ( $\text{mg L}^{-1}$ )	2.6	2.8	2.5	2.6	2.3
Suspended matter ( $\text{mg L}^{-1}$ )	34.7	25.9	24.5	28.9	23.1
Total Nitrogen oxides ( $\text{mg L}^{-1}$ )	1.569	1.662	1.384	1.391	1.326
Orthophosphates ( $\text{mg L}^{-1}$ )	0.054	0.093	0.089	0.066	0.080
Ammonium ( $\text{mg L}^{-1}$ )	0.17	0.17	0.10	0.11	0.10
<i>E. coli</i> (per 100 ml)	6888	9918	5972	4629	6957
<b>SWQI</b>	<b>79</b>	<b>79</b>	<b>83</b>	<b>81</b>	<b>85</b>

The regularity of the changes in the Danube water quality is obtained by the analysis of the given SWQI values in Table 2 for the period from 2005 to 2009.

Figure 3. graphically represents the changes in SWQI parameter values from two aspects, space and time, i.e. characteristic measuring points in the investigated time period. Surface 3D-graphs with continuous curves show

changes of average yearly values of water quality parameters (vertical axis) as a function of time and depending on the area along the Danube from the entry to the exit point in Serbia (horizontal axis). The presented results show trends of the SWQI parameters changes in time and space clearly and swiftly.

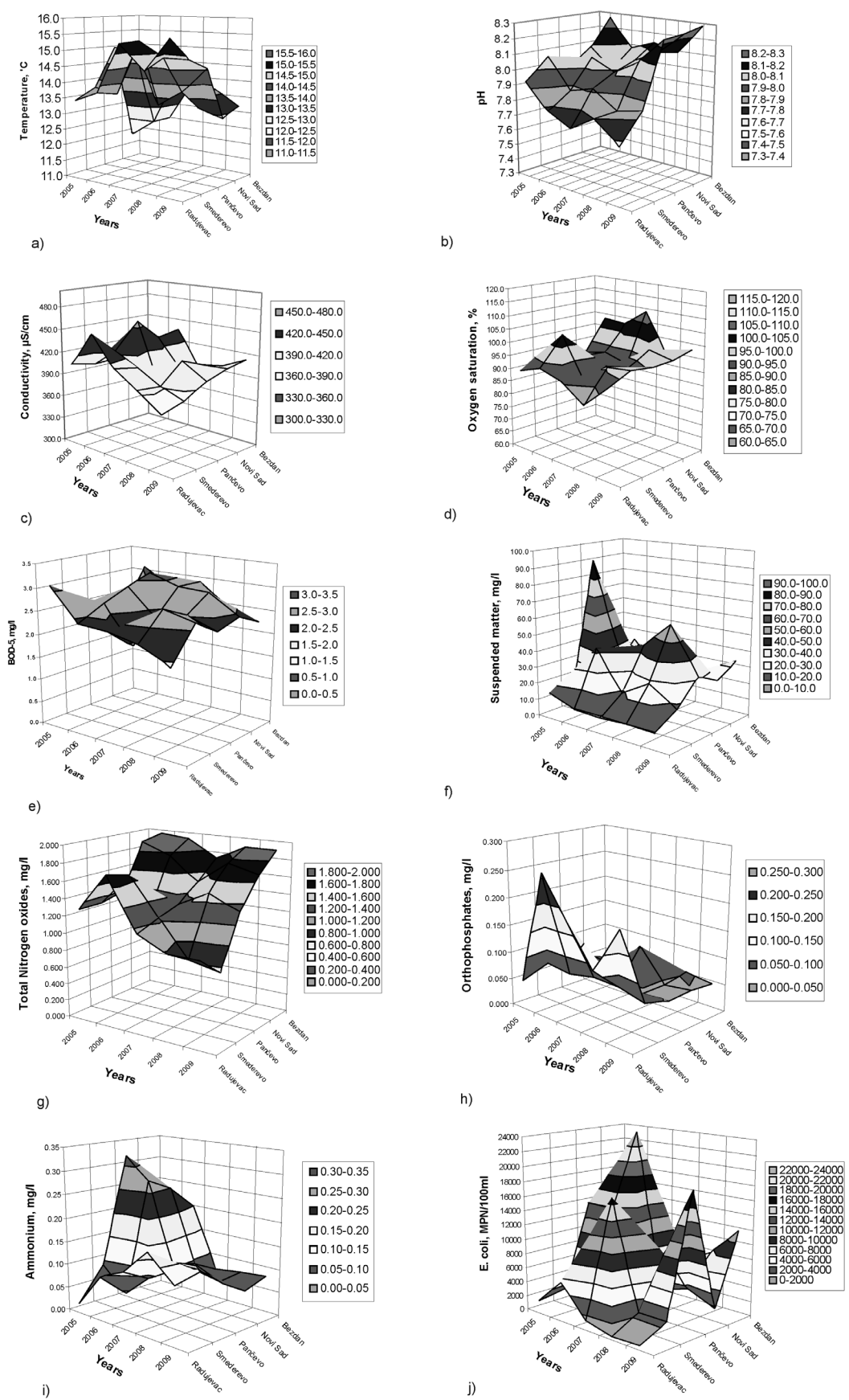
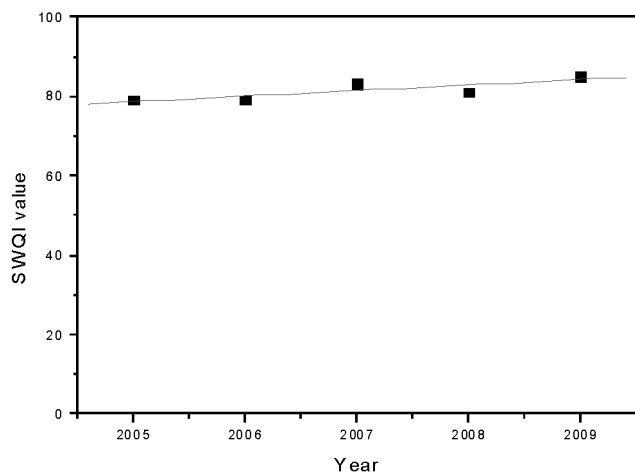


Figure 3. Trends of the measured SWQI parameters in time and space

Graphically, the variations of SWQI values of empirical series are expressed in a trend line that shows the average trend of the water quality for a longer period of time. Figure 4. gives the empirical series of SWQI values and linear fit with the average quality trend of 81.4 and the absolute growth of average + 1.4 SWQI index points for the quality of the River Danube water, in every year for the analyzed period. The Danube quality determined by a median of an arranged series of SWQI average values at the measuring points in Serbia over a five-year period shows a quality growth.



**Figure 4.** Linear trend of the River Danube water quality expressed by SWQI method

By applying the correlation classification criteria based on the average value of index points over the observed five-year period (SWQI = 81.4) it was found that the Danube water quality corresponds to Class II according to the legal regulations in Serbia, i.e. to Category A1 from the Directive 75/440/EEC for the surface water quality. A compatible analysis shows that the Danube water quality meets the required quality of the surface water.

## Conclusions

EU Water Framework Directive set a new, integrated approach to the protection, promotion and sustainable utilization of the European rivers. Some of the most important measures for the water resources protection are water monitoring, categorization and definition of water quality standards. Comparison and harmonization of the national legal regulations with the European methods for determination of indicators of the surface water quality is imperative for the development of water resources.

The presented investigation indicates that by using SWQI method, along with comparative analysis, a comprehensive assessment of the Danube water quality can be obtained. The applied SWQI method and the analysis results should be regarded as a contribution of the Republic of Serbia to European integrations in the field of the environment protection by implementation of WFD at the

national level. Integrated management of water resources sets new aims and standards in solving the pollution problems of the surface water.

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## Izvod

# PROCENA KVALITETA VODE DUNAVA U SRBIJI

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U radu je prikazana procena kvaliteta vode Dunava u skladu sa zakonskom regulativom Srbije, primenom metode Serbian Water Quality Index (SWQI) i Direktive 75/440/EEC. Praćenje kvaliteta površinskih voda sprovodi Hidrometeorološki zavod republike Srbije (RHMZ) čiji je fond podataka korišćen za period 2005-2009. godine. Komparativna analiza pokazala je nekompatibilnost parametara klasifikacije kvaliteta vode Dunava. Takođe, poznavanje ovih regulativa doprinosi boljem i pouzdanijem praćenju kvaliteta površinskih voda. Cilj ovog rada je da pokaže pripremu naše zemlje za integracione procese EU, kao i sve izazove i poteškoće u procesu implementacije Okvirne direktive o vodama Evropske Unije. Polazeći od Okvirne direktive o vodama kao nove „filozofije voda“ preporučene od strane EU, generalno nije jednostavno uskladiti srpsku legislativu sa novim pristupom integralnog upravljanja vodnim resursima.

**Ključne reči:** Dunav, SWQI, Direktiva 75/440/EEC.