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Surface Water Quality Assessment in Serbia - Water Quality Index and Ecological Status Comparison

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ABSTRACT: *Two composite indicators, widely applied as a tool for water quality assessment – Water Quality Index (WQI) and Ecological Status Assessment are compared in this paper. Since the mid-1970s, the WQI method has been successfully used in many countries to support reporting of water quality monitoring. The more recent Ecological Status approach is based on the WFD 2000/60/EC, which requires the classification of surface waters with respect to ecological status/potential assessment in EU Member States, by establishing water monitoring programmes for each river basin district. The results of surface water monitoring implementation in Serbia were used to compare these methods. Both mentioned methods reflect composite impact on water quality elements which support physical, chemical and biological parameters. Comparison of results obtained for parallel analysis of the same samples leads to conclusion that there is positive correlation between the outputs of these methods.. The analysis of advantages and deficiencies of both methods leads to the final conclusion - to what extent both methods are complement and/or substitute each other as a suitable tool for site-specific water quality assessment.*
KEYWORDS: *water quality, ecological status, surface water monitoring, indicators*

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I. INTRODUCTION

Surface waters are complex multi-component systems. The study of surface water depends on the selection and use of facts, principles and methods related to chemistry, physics, geology, hydrology, meteorology, mathematics and other sciences, to solve problems which essentially occurs in specific ecosystems. One of the consequences of technology revolution is a rapid increase in volume and availability of data as indicators of ecosystems. These data are necessary in order to make the best possible decisions in forming of social, economic and environmental policies. The common approach to avoid an overabundance of data is to use specific indices and indicators as a tool for generating information for decision-makers and the public in general.

The main feature of a water quality indicator is that it quantifies and simplifies environmental problems. Such indicator should be practical and realistic, created as a compromise between scientific accuracy and the information available from water quality monitoring data. Composite indicators can be used to summarize complex or multi-dimensional issues to support decision-making, particularly valuable for comparison between river basin districts. Nowadays, two composite indicators, Water Quality Index (WQI) and Ecological Status Assesment, are used worldwide as a tool for water quality assessment.

II. COMPOSITE INDICATORS AS A TOOL FOR WATER QUALITY ASSESMENT

Composite indicators became increasingly confirmed as a tool for summarizing complex and multi-dimensional issues in the following areas: economy, society and environment. A composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured (OECD, Glossary of Statistical Terms). Composite indicators, as a tool for measuring multi-dimensional concepts (e.g. water quality), illustrate more comprehensive survey of a state that cannot be assessed by a single indicator.

2.1. Water Quality Index assessment method

The WQI method is based on assessment of surface water quality. The WQI method uses index numbers within the range from 0 to 100, according to the selected quality parameters (Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Ammonia (NH_3), pH, Total Nitrogen (TN), ortho-Phosphates (o-PO_4), Suspended Solids (SS), Temperature (T), Conductivity, and Escherichia coli abundance), by determining a mutual factor that reflect water quality in general [1]. The mathematic formula of the WQI is:

$$SWQI = \sum_{i=0}^{n} q_i \times w_i \quad \text{...(1)}$$

The WQI index is derived by summing the individual products of water quality rating and corresponding weighting, where: WQI is the water quality index representing a number on the continuous scale from 0 to 100, n is the number of parameters, q_i is the water quality of the i-th parameter, and w_i is the weight related to the i-th parameter.

The process is repeated for n parameters (i.e. n = 10): DO, BOD_5, NH_3, pH, TN, o-PO_4, SS, T, Conductivity, and Escherichia coli abundance, and the WQI assessment system is provided in the Table 1.

Table 1. Calculation of weighted water quality ratings and WQIs

Parameter *	Unit	Value	Water quality rating, q_i	Weighting, w_i	$q_i \times w_i$
DO	% saturation	20.00	6	0.18	1.08
BOD	mg/l	9.00	15	0.15	2.25
NH_3	mg/l (N)	12.75	3	0.12	0.36
pH		7.50	99	0.09	8.91
TON	mg/l (N)	0.35	95	0.08	7.60
PO_4 (ortho)	mg/l (P)	0.03	94	0.08	7.52
SS	mg/l	28.00	53	0.07	3.71
T	ºC	8.50	99	0.05	4.95
Conductivity	µS/cm	540.00	24	0.06	1.44
E. coli	no./100ml	5000	77	0.12	9.24
				$\sum w_i = 1.00$	$\sum q_i \times w_i = 47.06$

Accordnig to the WQI method, the products of water quality ratings and weighting are summed; e.g. at i = 2, we have an input BOD_5 value of 9 mg/l and the corresponding rating q_i of 15 is obtained from the BOD_5 curve (Fig. 1). By multiplying this value, by the weighting factor w_2 of 0.15, the weighted water quality rating becomes 2.25. The weighted WQI = $\sum q_i$ x w_i = 47.06. The water quality data are obtained and transferred to weighted curve chart, from which a product of q_i x w_i is calculated.

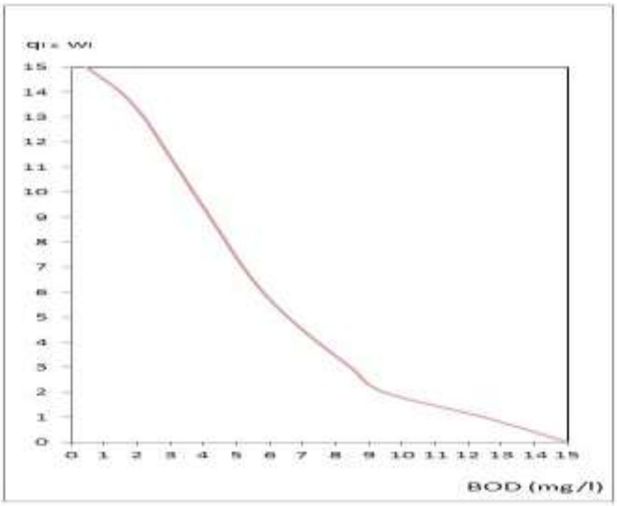

Figure 1: Water quality rating curve of Biochemical Oxygen Demand (BOD_5)

Following the WQI approach, the Serbian Environmental Protection Agency (SEPA) developed the Serbian Water Quality Index (SWQI), applied in the national environmental legislation and used to report to the public, professionals and policy decision-makers [2, 3]. On the national level, the WQI method has been modified to compare water quality indicators according to the national classification (surface water quality assessment system using five-class scale based on threshold values – Maximum Contaminant Levels (MCLs)), [4] (Table 2).

Table 2: Calculation of SWQI according to Maximum Contaminant Levels (MCLs)

Parameter (unit of measure)	Max. value qi x wi	MCL Class I	MCL Class II	MCL Class III	MCL Class IV
Dissolved Oxygen (%)	18	90-105 -	75-90 105-115	50-75 115-125	30-50 125-130
BOD_5 (mg/l)	15	2	4	7	20
Ammonia (mg/l)	12	0.1	0.1	0.5	0.5
pH	9	6.8-8.5	6.8-8.5	6-9	6-9
Total Nitrogen (mg/l)	8	10.05	10.05	15.5	15.5
ortho-Phosphates (mg/l)	8	0.005	0.01	0.01	0.01
Suspended Solids (mg/l)	7	10	30	80	100
Temperature (^oC)	5	-	-	-	-
Conductivity (μS/cm)	6	-	-	-	-
E. coli (MPN per 1000 ml)	12	2,000	100,000	200,000	200,000
$\sum(q_i \times w_i)$ = SWQI	100	85 - 84	69 - 71 74 - 71	44 - 48 56 - 52	35 - 36 51 - 46

The following values represent five-scale classification, based on the SWQI descriptors: 0 – 38 very bad, 39 – 71 bad, 72 – 83 good, 84 – 89 very good, and 90 – 100 excellent (Table 2). The I-IV classification of waters was used as the input threshold parameter for quantitative definition of the SWQI indicators over the entire range (0 to 100 index points) (Table 3).

Table 3: Classification of surface water quality according to the Serbian Water Quality Index

	Numerical indicator	Descriptor	Colour
Serbian Water Quality Index	100 – 90	Excellent	
	84 – 89	Very good	
	72 – 83	Good	
	39 – 71	Bad	
	0 – 38	Very bad	

The SWQI method classifies the surface water quality according to its purpose as well as a degree of cleanness:

a) Excellent – natural waters, after filtration and disinfection, can be used for municipal water supply and for food industry, and surface waters also to farm noble fish species (Salmonidae);
b) Very Good and Good – natural waters, can be used for bathing, recreation, water sports, farming of other fish species (Cyprinidae), and those which after treatment by contemporary methods can be used for drinking water supply and for food industry;
c) Bad – waters that can be used for irrigation and, after treatment by contemporary methods, also by industries, except for food industry;
d) Very Bad – waters which quality has an negative impact on the environment, only can be used after treatment using special methods.

A water quality according to the SWQI method can be assessed online using web application [5].

2.2. Ecological Status assessment method

In response to increasing threats to which aquatic systems are exposed, the European Union has established the WFD 2000/60/EC as well as several “daughter” directives, representing the first example of legislative framework for the protection of all water resources in Europe [6]. The main goal of the WFD is to enable long-term sustainable management of water resources based on a “high level” of protection of all surface waters, by achieving “good status” of surface water body, which means that both ecological and chemical status have been assessed as at least as “good”. A “surface water body” is a discrete and separately considered stretch of surface water, such as a lake, reservoir, stream, river or canal, part of a stream, river or canal, or brackish water.

The water quality elements used to assess the ecological status/potential in each surface water category (rivers, lakes, brackish (transitional) and coastal waters) have been divided into three groups: (1) biological elements; (2) hydromorphological elements supporting the biological elements; and (3) physico-chemical and chemical elements supporting the biological elements. The physico-chemical and chemical elements that support the biological elements include: general physico-chemical elements of water quality and specific nonpriority pollutants discharged in significant quantities into a water body [7]. The relationships between biological, physico-chemical, chemical and hydromorphological elements of water quality are shown in Fig. 2, [8].

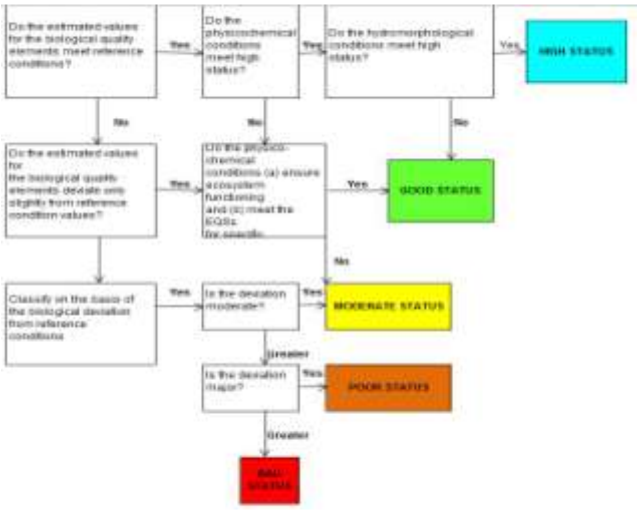

Figure 2. Relationships between biological, physico-chemical and hydromorphological elements of water quality in ecological status assessment

Besides ecological status assessment, the chemical status is assessed to determine the status of a water body, applying Environmental Quality Standards (EQS). The chemical status of surface waters is established in respect to threshold values of priority substances and priority hazardous substances. The EQS Directive (2008), also known as Annex X to the WFD, sets out maximum contaminant levels and average annual concentrations of priority substances and priority hazardous substances. The chemical status of a water body can be assessed as "good" if the proposed criteria are not exceeded. Additional contaminants were specified in the EQS Directive [9]. The chemical status of a water body is assessed as "achieved good status", if the threshold of the specified substances is not exceeded, or as "failing to achieve good status", if at least one of the specified threshold values is exceeded.

All of mentioned quality elements for the classification of surface waters, proposed in the WFD 2000/60/EC, constitute a tool for evaluating progress towards the achievement of the main goal laid down in Article 4 of the WFD – "good status of water". Based on threshold values of the quality elements, surface waters characterized by good status (according to the classification includes high and good ecological status) ensure proper conditions for the ecosystem function, fish protection (salmonids and cyprinids) and can be used for the following purposes: drinking water supply after treatment by filtration and disinfection, bathing and recreation, irrigation, and industrial purposes (process and cooling water).

The characterization of the class corresponding to "moderate ecological status" is provided on the basis of threshold values of quality elements, in terms of the conditions for life and fish protection (cyprinids) and can be used for: drinking water supply after treatment by coagulation, flocculation, filtration and disinfection, irrigation, and industrial purposes (process and cooling water). Surface waters which ecological status is "poor" can be used for drinking water supply combining the previously-mentioned treatments and advanced treatment methods, irrigation, and industrial purposes (process and cooling water). Surface waters with "bad ecological status" cannot be used for any purpose.

III. DATA ANALYSIS

Surface water quality data are based on monitoring programme, implemented by the Serbian Environmental Protection Agency, according to the appropriate national regulations adopted by the Serbian government. Water monitoring is carried out with monthly frequency including in total of 80 monitoring points (Fig. 3). The first surface water quality monitoring programme in Serbia harmonized with the WFD 2000/60/EC was launched in 2012.

In that respect, the set of parameters from the surface water monitoring programme, which includes general physico-chemical parameters, specific pollutants and biological quality elements (BQE), provides a comprehensive and integrated overview of surface water quality in a river basin district, as well as the fulfilment of criteria for a comparative quality assessment according to the SWQI and Ecological Status Assessment methods.

Figure 3. Surface water quality monitoring stations in Serbia in 2012

IV. RESULTS ON WATER QUALITY ASSESSMENT OF RIVER BASINS

The analyse of all water samples based on the SWQI method for the 2012-2016 period, primarily provided a snapshot of the physico-chemical quality of the rivers in the river basin districts (Fig. 4), [10, 11]. The Sava River Basin District is characterized by high water quality (with 96% of excellent, very good and good water quality, 4% of bad, and without samples in the very bad category), followed by the Morava River Basin District (where 9% of the samples are in category of bad and without samples in the very bad category). The worst water quality was assessed in the Danube River Basin District, where 19% of the samples were in the bad and very bad categories. The results of the ecological status of surface waters differ from those obtained by the SWQI method. Ecological Status Assesment method takes into account the functioning of aquatic ecosystems by determining the relationships between the biological, physico-chemical, chemical and hydromorphological quality elements.

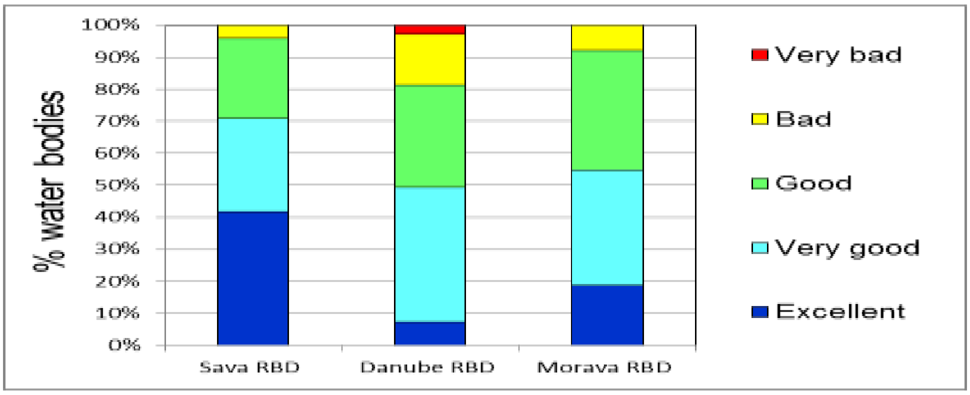

Figure 4: Serbian Water Quality Index (2012 – 2016 period)

In view of the main goal of the WFD (to achieve at least a "good status"), the Sava, Danube and Morava River Basin Districts can be ranked as follows: the ecological status of 10% of the samples from rivers in the Sava RBD was "good", the ecological status of 7% of the samples from the Morava RBD was "good", and without samples from the Danube RBD which ecological status assessed as "good" (Fig. 5), [12, 13].

Based on the definition of good ecological status, the rivers in the Sava RBD shows the best water quality. More than any other RBD, the threshold values of the quality elements in the Sava RBD ensure conditions for the functioning of ecosystems, life and fish protection (salmonids and cyprinids), and the water can be used for drinking water supply, after treatment by filtration and disinfection, bathing and recreation, irrigation, and industrial purposes (process and cooling water). The lack of samples with good ecological status, the presence of 18% of the samples with bad and 28% of the samples in poor status were from the Danube RBD. The rivers in that district is with the poorest water quality in Serbia and cannot be used for any purpose.

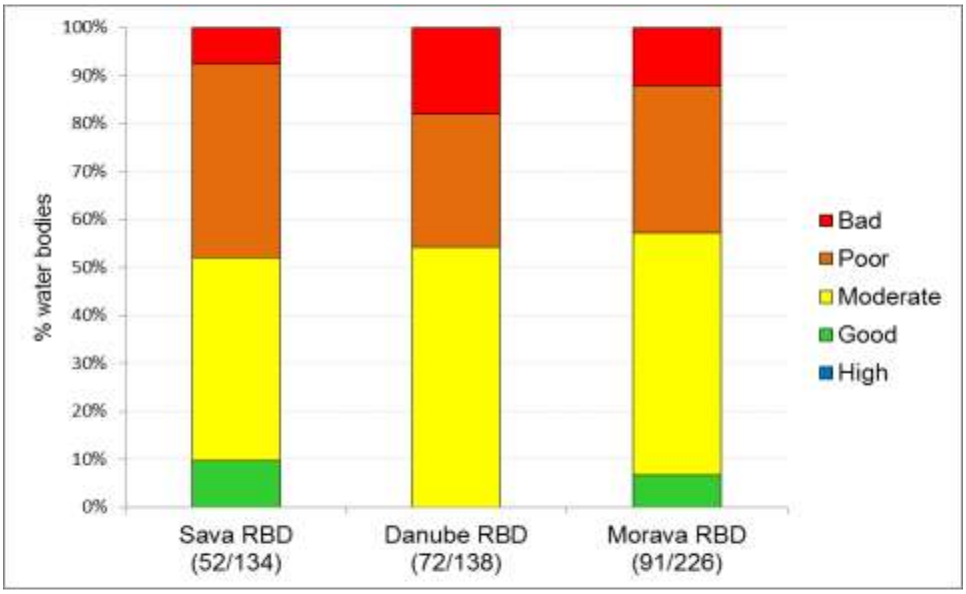

Figure 5: Ecological status (2012 – 2016)

Although WQI and Ecological Status Assessment approaches use different parameters, comparison of resulting status for the same water bodies obtained both by WQI and Ecological Status Assessment leads to conclusion that both approaches are in good correlation in general. Comparison of results obtained by analysis of the same samples of three different RBD by the both WQI and Ecological Status Assessment in four - years period are shown in Figures 4 and 5.

Graphic comparison of calculated SWQI and ES based on same data-set (same sampling stations in 2012-2016 period) for same rivers show interesting correlation – obtained water quality follow each other, but ES in all cases shows one water quality category lower than SWQI. The reason for that is higher percent of biological quality elements involved in calculation of ES. Biological quality elements (living organism in aquatic ecosystems) represent basis for ecological classification of waters, while some of physico-chemical parameters are primarily relevant for current and short-term pollution. On the other hand, living forms of aquatic ecosystems, due to their ability to accumulate pollutants, are best indicators of long-term pollution.

V. DISCUSSION – CHARACTERISTICS OF WATER QUALITY INDEX AND ECOLOGICAL STATUS ASSESSMENT

The common feature of the WQI and Ecological Status Assessment indicators is that they reflect the composite influence of different parameters (physical, chemical, biochemical), which are important for the ecological assessment and water quality management. They describe the suitability of surface water source for human consumption.

A deficiency identified by all critics of such an approach is that it represents the general water quality and that information on single variables is lost when the composite indicator (numerical or descriptive) is generated. Also, not all health risks can be analyzed for the definitive assessment of water quality without taking into account all of the microbiological and chemical pollution indicators.

Separately, the WQI and Ecological Status Assessment have different advantages and disadvantages, which could clearly be identified in the analysis conducted as a part of this research on the basis of river basin monitoring in Serbia (Figs. 4 and 5). The advantage of WQI is that is aggregates water quality data into a single index, simply to understand and easy to apply. This feature has contributed to widespread application and development of this method with different quality variables. Thus SWQI, apart from being used for national reporting, including its classification of quality levels, has been accepted for national environmental status reporting in neighbouring country (Montenegro) [14, 15]. The experience of the Serbian Environmental

Protection Agency with regard to the application of this method and reporting is that SWQI is a clear and intelligible surface water quality evaluation tool for managers and professionals.

The advantage of the Ecological Status Assessment method is its adaptability to different legal requirements and different water use. The deficiency is a lack of information about the objectives specific to each location and particular water use. The WFD established the Ecological Status Assessment method for water quality monitoring in the European Union. Its main objective is achieving a "good status" of all surface waters. With regard to water management, monitoring of physico-chemical, chemical and biological indicators is the main starting point for evaluating the effectiveness of the water pollution control policy in Serbia. Hence, informed policy decisions are associated with the reliability of the quality monitoring programme, which implementation results in water quality assessments applying the WQI and Ecological Status Assessment approaches.

The results of surface water quality monitoring are the framework that provides information about the interactions between human activity and water resources. The interactions are represented by the DPSIR (Driving Force – Pressure – State – Impact – Response) framework, which reflects all causal relationships [16]. The results of surface water quality assessment correspond to this framework (Fig. 6). Thus the Driving Force is human activity that impacts the environment (e.g. population growth, manufacturing) and Pressure is the direct consequence of such activity (e.g. amounts of wastewater discharged by the sewage system). On the other hand, State indicates the current status of the environment (e.g. recipient quality as a result of wastewater discharges, physico-chemical and biological indicators), while Impact is the consequence of the pressure on the environment (e.g. dead fish). The indicators of social Response describe the measures or investments and other reactions to changes in environmental status (e.g. proportions of treated or recycled wastewaters).

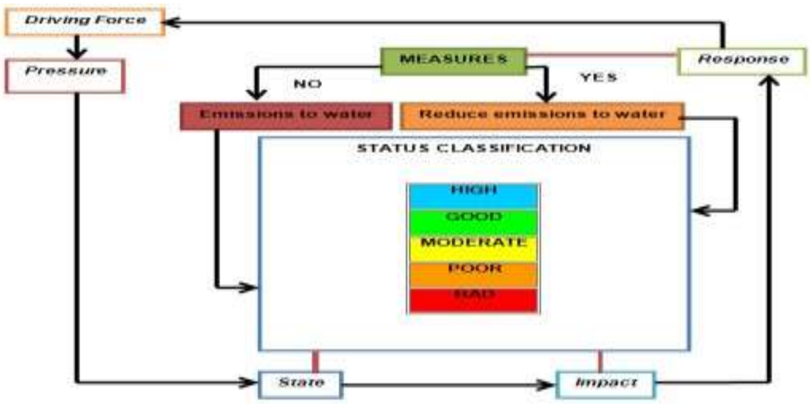

Figure 6. Causal relationship between human activity and water resources - surface water quality assessment

An important component of water management policy planning and implementation is founded upon information supply, consultation and involvement of the public, including users. In order to ensure the participation of the general public in the establishment and updating of river basin management plans, appropriate information needs to be provided about planned measures and progress of implementation [17]. In this regard, the main indicators are the results of surface water quality assessment based on the WQI and Ecological Status Assessment method.

VI. CONCLUSIONS

From the present study of two water quality indicators – Water Quality Index (WQI) and Ecological Status Assessment, it was concluded that their purpose has been fulfilled as they assign a single value to the water quality of a source, by reducing a large number of parameters to a simple expression that results in easy interpretation of water quality monitoring data. Still, composite indices – the WQI and Ecological Status Assessment can be useful for summarising data and information for decision-makers and may be particularly valuable for comparison between countries.

The advantage and main feature of the Ecological Status Assessment approach is that it takes into account changes in concentrations of chemical pollutants, the biological quality elements (BQE), and the hydromorphology of a certain location (water body). However, the complex interactions among the variables, which reflect site-specific conditions, physico-chemical water quality and biological quality elements, pose a risk of "bias" in the final evaluation because the method "covers" chemical and/or "emphasises" the importance of biological quality elements. The advantage of the WQI is that it considers all physico-chemical and microbiological water quality variables equally important, such that their weights (w_i) affect the overall quality assessment (q_i x w_i). Consequently, this indicator is unequivocal in the descriptive assessment of quality because the descriptors correspond to numerical values, which is an important aspect of communications between professionals and the public, on one hand, and decision-makers on the other. The analysis of the advantages and deficiencies of the two methods in the present case study of river basins in Serbia leads to a conclusion that answers the question: Can these two methods complement and/or substitute each other as a suitable tool for evaluating the water quality on a certain location?

The WQI and Ecological Status Assessment methods are complementary and can substitute each other for the assessment of surface water quality, in view of the following:

a) They can substitute each other because the different parameters they address do not lead to the same unit of measure.
b) They complement each other because they offer the possibility to compare, in temporal and spatial terms, the quality of water bodies in the event of sudden accidental pollution.
c) They complement each other because they provide a picture of the water quality status for various purposes and users.

In 2000, the Water Framework Directive (WFD) established a framework for the management, protection and improvement of the quality of water resources across the EU. The goal of European and national water policies is to ensure that throughout Europe, a sufficient quantity of good-quality water is available for people's needs and the environment. Achieving good water status means meeting certain ecological, chemical, morphological and water quantity standards. Water quality indices, the Ecological Status per the WFD and the WQI at national and regional levels, with their specific characteristics, are extremely important for the establishment of adequate plans for water resources management activities.

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