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Review Paper

ANALYSIS OF THE USE OF INDEXING METHODS IN WATER QUALITY ASSESSMENT

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Abstract. *This paper presents the terminological definitions of indexing methods and the possibilities of their use in different scientific areas. Additionally, the paper identifies the most relevant indexing methods for water quality assessment with an overview of how they are applied in Serbia. Serbia has adopted a National List of Environmental Protection Indicators in order to establish, operate, develop, coordinate, and maintain a unified information system for environmental protection. National indicators of a country are used throughout that country and have a general and mandatory character. The paper highlights the importance of indicators and helps to better understand the importance and the purpose of using indexing methods in the assessment of environmental quality and safety parameters and in the field of water protection. The aim of the paper is to analyze the most relevant indicators and indices used in water management in Serbia. The paper specifically focuses on the importance of using the water pollution index and its correlation with other water protection indices.*

Key words: *SWQI, saprobic index, drinking water quality index, water pollution index*

1. INTRODUCTION

Indicator and *index* are Latin words denoting a gauge, a sign, a thing that indicates the state or level or something and brief content; thus, the two words are sometimes synonymous [1]. Considering their etymology, it may be said that indices connect different indicators into a single number that can be used for comparison in time and space, which is why complex (composite) indicators are often referred to as indices in the literature, whereas the term *indicator* usually refers to single indicators [2]. By means of indicators, specific phenomena related to performance can be observed, identified, and explained, whereby one or more indicators may be identified for a single phenomenon. Indicators represent content that can be used to identify and measure a specific variable

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and compare it with other variables [3]. Indicators are usually introduced as indirect and partial measurements of complex phenomena that are difficult to measure directly [4]. In fact, indices and indicators are instruments intended to reduce large amounts of data to the simplest form while preserving the essence of those data and they have the added bonus of being fairly compact and having easily understandable goals [5]. Owing to their broad application in different scientific fields, there is no unique definition of indicators. The WHO defines indicators as "variables which help to measure changes", directly or indirectly [6]. The Serbian Law on Environmental Protection stipulates that environmental quality is the state of the environment expressed using physical, chemical, biological, esthetic, or other indicators [7].

Measurement is a process in which an indicator assumes a specified value, while analysis involves the interpretation of indicator values and decision-making based on the obtained values [8]. A good indicator primarily needs to provide valid data, to be transparent and easy to understand, to be easily computed, and to be readily comparable [9]. Figure 1 shows the different levels of data that form the "information pyramid", with "data" at the bottom that, if not processed, have little use value. However, when data are processed into statistical reviews or tables, they can be used in reports or as a basis for making certain estimates [5].

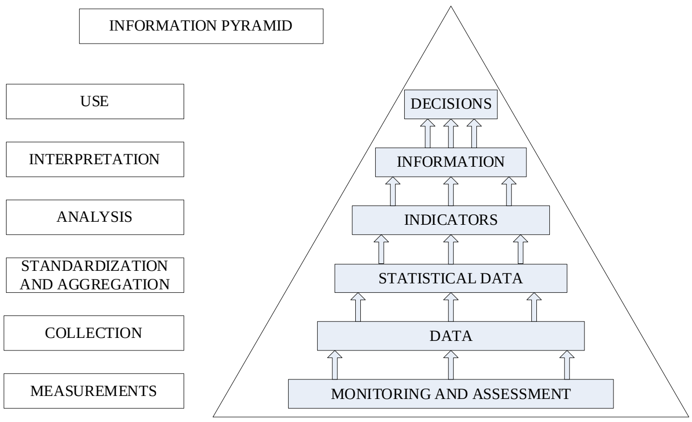

Fig. 1 Information pyramid – indicators as a tool to obtain information [5]

Since the environment abounds with a variety of complex and dynamic phenomena, processes, and relationships, potential current activities in the entire cycle produce a large amount of information. Therefore, it is necessary to reduce the abundant information to a limited number of objective indicators. The operation of integrating different indicators into an index, or compressing the information, is called aggregation [10]. Based on the calculated indices and the application of proper criteria, a specific position is adopted, the organization of planned actions is interpreted, and decisions are made and implemented, all for the purpose of protecting the environment.

2. Use of Indexing Methods in Water Quality Assessment

Any measurement of water quality parameters can be used as an indicator; however, there is no measurement that could describe the overall water quality of any single body of water, let alone of global water resources [11]. Aggregation of selected parameters yields a composite indicator, or an aggregate index, which contains individual indicators and their corresponding weight coefficients [9]. Weight coefficient values are calculated as the specified share of each individual indicator in relation to the I-distance values and based on Pearson correlation coefficients. Even though there is no universally accepted composite index of water quality, some countries and regions used or are currently using unified data on water quality to develop their own water quality indices. In addition to the mentioned indexes, the state of water quality can be analyzed using selected physical and chemical parameters, all with the aim of monitoring and identifying locations with potential sources of pollution in the watershed of the selected watercourse [12].

2.1. Serbian Water Quality Index (SWQI)

The Serbian Environmental Protection Agency developed the environmental indicator for the domain of waters, which is used to inform the public and experts on the state of water quality. For the thematic area of waters, the Rulebook on the National List of Environmental Protection Indicators ("Official Gazette of the Republic of Serbia", No. 37/2011), among others, defines the SWQI state indicator, which provides environmental information or describes environmental phenomena at the national level [13]. The indicator is based on the Water Quality Index method (Development of a Water Quality Index, Scottish Development Department, Engineering Division, Edinburgh, 1976), according to which ten parameters of physicochemical and biological quality are aggregated into a composite indicator of surface water quality. In the Water Quality Index (WQI) method, the quality (qi) of ten selected parameters (oxygen saturation, BOD5, ammonium ion concentration, pH value, total nitrogen, orthophosphate concentration, total suspended solids, temperature, electrical conductivity, and presence of fecal coliform bacteria) represents the characteristics of surface waters by reducing them to a single index number. The share of each parameter in the total water quality does not have the same relative significance, which is why each of them received their own weight (wi) and a number of points according to the share in quality deterioration. The sum of the products (qi × wi) yields the index of 100 as the ideal sum of the shares of all parameters. In case a parameter lacks a piece of data on the quality, the value of arithmetically obtained WQI is corrected by multiplying the index with 1/x, where x is the sum of arithmetically obtained weights of available parameters [14]. The SWQI method represents an essential IT tool that provides reliable data about long-term trends, which is important in developing water pollution risk management models [15].

The adopted classification criterion for the descriptive quality indicator and the designation of surface water class based on the calculated SWQI number are given in Table 1.

Table 1 Surface water classification using the Water Quality Index method [14]

SWQI	90-100 89-84	83-72	71-39	38-0
Descriptive indicator	Excellent Very good	Good	Poor	Very poor
Water class	I	II	III	IV

Through a correlation with the Statute on Water Classification ("Official Gazette of the Socialist Republic of Serbia", No. 5/68), which classifies water into classes I, II, IIa, IIb, III, and IV based on indicators and their threshold values, the Serbian Water Quality Index (SWQI) was established, comprising five descriptive categories of quality (excellent, very good, good, poor, and very poor). Surface water quality indicators are classified according to the intended water use and degree of purity while being compatible with the existing classification:

- Excellent – with additional filtration and disinfection, water is usable in its natural state for residential water supply and in food industry, while surface waters can be used as fisheries for noble species;
- Very good and good – water usable in its natural state for swimming and recreation, water sports, as fishery for other species, or, provided a modern treatment method has been used, for residential water supply and in food industry;
- Poor – water used for land irrigation or, after treatment by modern methods, in any industry except food industry;
- Very poor – water quality detrimental to the environment, usable only after special treatment methods have been applied.

The adopted classification criterion for the descriptive water quality indicator based on the calculated SWQI number is given in Table 2.

Table 2 Classification criterion of the SWQI descriptive indicator

	Index	Descriptive indicator	Color
Serbian Water Quality Index	100-90	Excellent	
	84-89	Very good	
	72-83	Good	
	39-71	Poor	
	0-38	Very poor	

The Rulebook on the National List of Environmental Protection Indicators emphasizes the importance of SWQI indicator as being easy to understand, because indicator value changes can simply be associated with deterioration or improvement of an observed environmental phenomenon.

A good example of a SWQI indicator application is the use of this method to determine the SWQI of Lake Palić (Table 3) and Nišava river (Table 4).

Table 3 SWQI of Lake Palić for 2018 by month [16]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SWQI	58	57	62	58	46	36	40	45	59	60	60	56

Based on the obtained data and according to the Rulebook on Parameters of Surface Water Ecological and Chemical Status and Parameters of Groundwater Chemical and Quantitative Status (“Official Gazette of the Republic of Serbia”, No. 74/11), it can be concluded that an acceptable status of the lake was not achieved.

The Institute of Public Health in Niš published its results of Water Quality Index for the river Nišava in January 2016. Measurements were conducted on five measuring stations. The calculation results of SWQI based on the measurement results are presented in Table 4.

Table 4 Published results of SWQI for the river Nišava in January 2016 [17]

Nišava - village Prosek	Nišava – in the level of water intake system NAISSUS	Nišava – 100 m upstream from where the sewage collector flows into the river	Nišava – 300 m downstream from where the sewage collector flows into the river	Nišava – 100 m river empties into the South Morava
86 – Very good	86 – Very good	82 – Good	83 – Good	80 – Good

The highest SWQI value is recorded on the measuring station in village Prosek and in the level of the water intake system NAISSUS with the value of 86, which corresponds to the descriptive indicator "very good" (classification interval 84 – 89), i.e. to class I of surface water. The lowest SWQI value is recorded on the measuring station Nišava – 100 m river empties into the South Morava, with the value 80, which corresponds to the descriptive indicator "good" (classification interval 83 – 72), i.e. to class II of surface water.

2.2. Saprobic index (SI)

In addition to the SWQI, the Rulebook on the National List of Environmental Protection Indicators also defines the saprobic index (SI). Generally, saprobity is the biological state of water determined by the presence of a specific quantity of organic substances subject to biodegradation and it is an important factor of water quality. Over a century ago, Kolkwitz and Marsson [18,19,20] laid the foundations of saprobiology by introducing the concepts of biological indicators of water pollution and the so-called saprobic systems. The SI is a biological indicator of water status used in the assessment of organic pollution levels and it can rely on different groups of aquatic organisms as indicators. The degree of saprobity reflects the intensity of organic matter degradation in an ecosystem. The EU Water Framework Directive (2000/60/EC) recommends the definition of SI threshold values for a water type or water type group. The SI is determined using the Pantle & Buck method (1955) [21]:

$$SI = \frac{\sum_{i=1}^{n} a_i \cdot s_i}{\sum_{i=1}^{n} a_i}, \tag{1}$$

where:
a_i – the number of organisms per unit volume or area;
s_i – individual saprobic index of species i.

All groups of aquatic organisms – algae, aquatic microphytes, zooplankton, microzoobenthos, aquatic macroinvertebrates, and fish – may be used as indicator organisms. Water is classified according to SI values as follows [14]:

- oligosaprobic (SI = 1-1.5);
- β-mezosaprobic (SI = 1.5-2.5);
- α-mezosaprobic (SI = 2.5-3.5);
- polysaprobic organisms (SI = 3.5-4).

The indicator is either expressed numerically or presented as a quality class. It is calculated in bulk, for the water area and/or at the national level, as the median of mean annual values. According to the Statute on Water Classification in the Republic of Serbia (1978), each zone corresponds to a specific water quality class – oligosaprobic corresponds to class I water quality, β-mezosaprobic to class II, α-mezosaprobic to class III, and polysaprobic to class IV [22]. Saprobic systems are used in many countries throughout the world and they have become an unavoidable step in biological monitoring of aquatic systems aimed at water quality assessment.

The Institute for Public Health in Subotica also determined the SI for Lake Palić in 2018, but no saprobity changes were observed at the measurement locations during that year. SI values indicate that the water at every measurement location was of class II quality during every month except January and April, when the quality was reduced to class II-III [16].

2.3. Drinking water quality index

The drinking water quality index is another important indexing method used in water quality assessment. Drinking water quality monitoring is only as good as the collected data, so it is necessary to expend great efforts to ensure that the data are representative, reliable, and completely valid. This should be a matter for the responsible persons in water supply companies, local self-governments, public health services, and the health inspectorates. Hygienic safety of drinking water is ensured through systematic inspections, whose frequency depends on the average daily produced water over a year (m^3/day) according to the current Rulebook [23]. The methodological approach to the assessment of the impact of water quality on health using the descriptive index of drinking water quality risk and its corresponding unsafety percentage is shown in Tables 5 and 6 [24]. Qualitative health impact indicators are determined as the risk of exposure to microbiological (Escherichia coli, Enterococcus) and physicochemical agents, such that they never exceed the threshold concentrations.

The index pertains to the share of drinking water samples that do not meet the prescribed parameter values in the total number of samples obtained from local water supply companies and other sources. The control involves systems serving more than five households, or more than 20 people, as well as water supply from the facilities owned by companies or other legal entities and entrepreneurs who manufacture and/or sell staple food, or supply it to public institutions (educational, tourism, hospitality, transport, etc.). The indicator is calculated as the quotient of the number of unsafe samples and the total number of samples multiplied by 100 (physicochemical and biological indicators), as a sum or individually for the said groups of consumers.

Table 5 Index according to biological unsafety [23]

Level	Unsafety %	Description
1	< 2	Insignificant
2	2.1-5	Low
3	5.1-10	Moderate
4	10.1-25	High
5	> 25	Severe

Table 6 Index according to physicochemical unsafety [23]

Level	Unsafety %	Description
1	< 5	Acceptable
2	5.1-10	Partially acceptable
3	10.1-20	Poor
4	20.1-50	Very poor
5	> 50	Alarming

The drinking water quality index provides information about the risks of negative impacts of drinking water on human health and indicates to what extent the drinking water supply complies with the health and hygiene standards and requirements.

2.4. Water pollution index (WPI)

The water pollution index (WPI) method is most often used by different authors as a simple indicator of river watershed pollution. The WPI is an arithmetic method of integrating parameters for the assessment of surface water chemical and ecological status [25]. It is a combined physical and chemical index that allows water quality comparison between different bodies of water.

Using physical and chemical parameters, the WPI simplifies water pollution assessment. It is calculated as the sum of the ratios between the average annual value (Ai) and standard threshold values (T) for each parameter divided by the number of parameters used (n)

$$WPI = \frac{1}{n}\sum_{n=1}^{n}\frac{Ai}{T}\ . \tag{2}$$

Current regulation defines the target allowed concentrations of specific parameters for the given classes of ecological status. Standard threshold values are country-specific and Serbia includes them in the national regulation (Official Gazette of the Republic of Serbia, No. 74/2011). The standard threshold values for class I are given in Table 7.

Table 7 Standard threshold values (T) for class I

Parameter	Measurement unit	Standard threshold values (T)
pH	/	8.5
DO	mg/L	8.5
BOD5	mg/L	2
TOC	mg/L	2
NH_4-N	mg/L	0.1
NO_3-N	mg/L	1
PO_4-P	mg/L	0.02
TP	mg/L	0.05
Cl^-	mg/L	50

Based on the obtained WPI values, water courses are classified into different quality classes, as shown in Table 8. If WPI < 1, a water course is designated as pure, and if WPI > 2, a water course is polluted; in case WPI > 6, a water course is deemed heavily polluted [26].

Table 8 Water quality classification based on the WPI

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

This paper relies on the most recent available data on the Ibar River water quality, for 2017, 2018, and 2019, published in the annual reports on the surface and groundwater quality by the Serbian Environmental Agency, which operates under the auspices of the Serbian Ministry of Environmental Protection.

Testing of the Ibar River water quality involved three small hydrological measuring stations at three measurement locations – Batrage, Raška, and Kraljevo. Analysis was conducted for nine physicochemical parameters: pH value, dissolved oxygen (DO), biochemical oxygen demand (BOD5), total organic carbon (TOC), ammonium ion (NH_4-N), nitrates (NO_3-N), orthophosphates (PO_4-P), total phosphorus (TP), and chlorides (Cl). Table 9 shows the average annual values of physicochemical parameters at Ibar River measuring stations for the abovementioned years.

Table 9 Average annual values of physicochemical parameters at Ibar River measuring stations for 2017, 2018, and 2019

Year	Station	pH	DO mg/L	BOD5 mg/L	TOC mg/L	NH_4-N mg/L	NO_3-N mg/L	PO_4-P mg/L	TP mg/L	Cl mg/L
2017	Batrage	8.4	12.4	1.7	2.8	0.07	0.47	0.044	0.068	7.8
	Raška	8.3	11.5	2.6	3.5	0.16	0.01	0.109	0.243	12.4
	Kraljevo	8.4	12.1	2.5	4.1	0.10	0.01	0.083	0.198	9.1
2018	Batrage	8.3	10.8	1.5	2.7	0.04	0.71	0.027	0.057	5.9
	Raška	8.3	10.7	1.8	2.7	0.08	0.90	0.046	0.070	6.8
	Kraljevo	8.2	9.7	3.0	5.2	0.12	1.35	0.090	0.256	11.8
2019	Batrage	8.2	9.7	2.6	4.5	0.12	1.45	0.099	0.242	13.1
	Raška	8.3	11	2.9	4.5	0.10	0.03	0.075	0.190	11.3
	Kraljevo	8.3	11.1	2.3	3.5	0.10	1.25	0.080	0.227	10.8

The average WPI values for the observed periods were calculated based on comparisons between the average annual values of the listed parameters (Table 9) and the defined standard threshold values for class I water quality (Official Gazette of the Republic of Serbia, No. 74/ 2011) (Table 6). The results obtained using the WPI method are shown in Table 10 and Figure 2.

Calculated WPI values indicate that pollution levels differ among the three measuring stations, as illustrated in Figure 2.

WPI assessment in terms of nine physicochemical parameters of the ecological water quality status of the Ibar River for 2017, 2018, and 2019 shows that the water pollution is characterized as ‘moderately polluted’, corresponding to class III surface water quality.

Table 10 WPI values, water classes, and characteristics at Ibar River examination sites

Year	Station	WPI	Class	Characteristics
2017	Batrage	1.064	III	Moderately polluted
	Raška	1.949	III	Moderately polluted
	Kraljevo	1.668	III	Moderately polluted
2018	Batrage	0.896	II	Pure
	Raška	2.067	IV	Polluted
	Kraljevo	1.64	III	Moderately polluted
2019	Batrage	1.11	III	Moderately polluted
	Raška	2.039	IV	Polluted
	Kraljevo	1.79	III	Moderately polluted

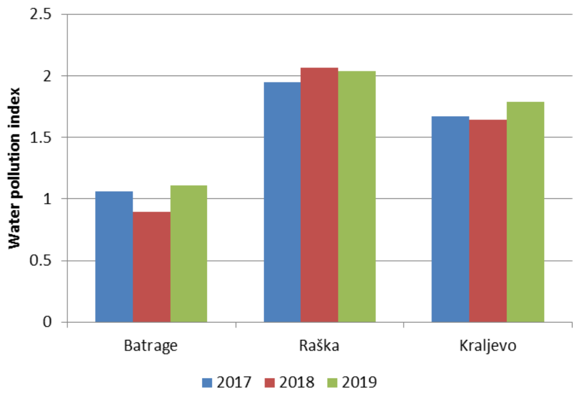

Fig. 2 Graph of WPI at different measuring stations for 2017, 2018, and 2019

3. CONCLUSION

Numerous and various environmental indicators are in use today, reflecting the state of the environment and accompanying the realization of set goals through plans, strategies, and policies. This paper presented the three most commonly used indicators in water quality assessment in Serbia – Serbian Water Quality Index, saprobic index, and drinking water quality index – as well as one indicator (water pollution index) that is still not used in Serbian legislation. Therefore, it can be concluded that the use of indexing methods in such a complex domain as the environment, more specifically water, with an abundance of available data, is of paramount importance because it provides a means to obtain comparable data. It should be particularly emphasized that the monitoring of composite indices is very useful for making different decisions and implementing water management measures. Serbia's preparation for EU accession involves the harmonization of the national water legislation with EU directives, which is why the presented indexing methods for water quality assessment are such important and suitable tools.

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ANALIZA PRIMENE INDEKSNIH METODA U OCENI KVALITETA VODA

U radu je dat prikaz pojmovnog određenja indeksnih metoda, kao i mogućnosti njihove primene u različitim naučnim oblastima. Takođe, izvršena je identifikacija najznačajnijih indeksnih metoda u oblasti ocene kvaliteta voda, sa osvrtom na primenu u Republici Srbiji. Shodno tome u Republici Srbiji usvojena je Nacionalna lista indikatora zaštite životne sredine u cilju uspostavljanja, vođenja, razvijanja, koordinacije i održavanja jedinstvenog informacionog sistema zaštite životne sredine. Nacionalni indikatori su oni koji se primenjuju na nivou jedne zemlje i imaju opšti i obavezujući karakter. Rad ukazuje na važnost indikatora i pomaže boljem shvatanju značaja i suštine primene indeksnih metoda u oceni parametara kvaliteta i bezbednosti životne sredine, odnosno u oblasti zaštite voda. Glavni cilj rada je analiza najznačajnijih indikatora i indeksa koji se primenjuju u oblasti voda u Republici Srbiji. Pored toga, u radu je poseban osvrt dat na značaj primene indeksa zagađenja voda, kao i primer korelacije sa ostalim indeksima u oblasti zaštite voda.

Ključne reči: *SWQI, indeks saprobnosti, indeks kvaliteta vode za piće, indeks zagađenja voda*