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Application of the Water Pollution Index in the Assessment of the Ecological Status of Rivers: a Case Study of the Sava River, Serbia

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Abstract: Water quality and status assessment of water bodies could be based on a large number of various parameters, including physical, chemical, hydromorphological, microbiological and biological. Often it is difficult to interpret the results of water status assessment when numerous quality elements are analysed, since each may indicate different quality class. The Water Pollution Index (WPI) overcomes this problem by providing a single assessment score. Previously, WPI was calculated using physical and chemical parameters combined with microbiological parameters. Biological quality elements are recommended by the EU Water Framework Directive (WFD) as obligatory for the assessment of ecological status of water bodies. For the first time in this study, the index was modified to include also biological parameters. Sampling and field measurements were done in 2007–2011, at three sites on the Sava River in the Belgrade region. According to the obtained WPI values, the river was assessed as polluted in 2007, moderately polluted for the period 2008–2010 and slightly polluted ("pure") in 2011. This result shows an overall improvement of the water quality during the period of examinations. Our study demonstrates that the WPI could be effectively used as a metric for ecological assessment according to the requirements of the WFD. It should be further elaborated to provide type- and stressor-specific assessment system.

KeyWords: Water Pollution Index, biological quality elements, ecological status, Sava River

Introduction

The quantification of water quality changes is inherently problematic. However, there are a number of specific indicators that represent different aspects of water quality, which can vary in its significance in different geographical regions (Walsh, Wheeler 2012). Furthermore, it can be difficult to convey relevant water quality information to policy makers and the public (Walsh, Wheeler 2012).

There is an array of indices used for the assessment of water quality based on physical, chemical or biological parameters, separately. Development history of these indices is discussed by many authors (e.g., Rosenberg, Resh 1993, Chapman 1996, AQEM 2002).

Often, it is difficult to interpret the results when numerous parameters are used for the evaluation of water quality, especially considering that single parameters reflect the influence of diverse pressures and could show different quality classes. On the other hand, the use of one or few metrics reduces the confidence of the assessment system. In practice, in multimetric assessment systems, usually the parameter of the poorest quality is used as determinant of the quality class (Simonović et al. 2007). The EU Water Framework Directive (Directive 2000/60/EC – WFD), requires the evaluation of the water quality status through estimation of the ecological and chemical status of the water bodies. Hence, there is

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a need to interpret the results in a simple, objective, and realistic manner by combining a large data set of physical, chemical and biological quality elements into a single performance assessment.

The Water Pollution Index (WPI, Lyulko et al. 2001, Filatov *et al.* 2005) represents an arithmetical way of integrating parameters for assessing the chemical and ecological status of inland waters. WPI, based on physical and chemical parameters, has already been used for rivers of Latvia (Lyulko et al. 2001), Greece (Nikolaidis *et al.* 2008), and Serbia (Milijašević *et al.* 2011, Brankov *et al.* 2012), as well as for the White Sea (Filatov *et al.* 2005). These studies show that the use of this index simplifies the evaluation of the status and that it is suitable for application for different water body types. The advantage of the WPI index is that it allows combination of different parameters; in addition, there is no limitation in the number or types of the used parameters. In our case, we included parameters derived from the biological quality elements (BQE).

The Sava River is the biggest tributary of the Danube River and it flows 62 km through the city area of Belgrade. It supplies Belgrade with potable water and it is a recipient of waste waters. One of our study sites (Makiš) is the main source of water supply for Belgrade. According to the national regulation, the Sava River belongs to type 1: lowland watercourse with domination of fine sediment (Official Gazette RS 74/2011). The river in the studied stretch is under significant influence of various pressures, including organic and nutrient pollution, industry and hydromorphological degradation (Paunović *et al.* 2012).

The aim of this article is to test a modification of the WPI, in which for the first time biological indices were included together with physical, chemical and microbiological parameters.

Materials and Methods

During the investigated period (2007–2011), samples were collected at three localities along the Sava River in the Belgrade region (Fig. 1): Zabran (N 44°40'06" E 20°14'40"), Duboko (N 44°44'06" E 20°18'14") and Makiš (N 44°45'34" E 20°21'24").

Physical and chemical water properties were measured once a month (March-October) *in situ* and in the laboratory of the Institute of Public Health, Belgrade, Serbia. Water samples were taken with Friedinger's bottle, volume 3 L, from 0.5 m depth, at all three localities, using standard methods (APHA AWWA WEF 1995, SRPS ISO 5667/2008, SRPS ISO 7828/1997, SRPS ISO 5667-6: 1997, SRPSEN ISO 5667–3: 2007, SRPS EN ISO 5667–1: 2008).

Water pH, conductivity (µS/cm), dissolved oxygen (DO; mg/l O_2), oxygen saturation (%), nitrites (NO_2 mg/l N; PRI P-V-32/A) and nitrates (NO_3; mg/l N; EPA 300.1) were measured with Horiba W-23XD multiparametric probe (HORIBA Instruments Incorporation, USA) in the field. We measured 5-day biochemical oxygen demand (BOD_5; mg/l O_2; SRPS ISO 5813: 1994, SRPS EN 1899–2: 2009), chemical oxygen demand (COD; mg/l O_2; SRPS ISO 6060: 1990), total organic carbon (TOC; mg/l C; SRPS ISO 8245:1994), total phosphates (mg/l P; EPA 207. Rev 5, SRPS ENISO 6878: 2008), suspended particles (mg/l; SMEWW 19th method 2540 D), ammonium ion (NH_4; mg/l N; PRI P-V-2A), chlorides (Cl; mg/l Cl; SRPS ISO 9297: 1994) and metals Zinc (Zn), Copper (Cu), Arsenic (As), Iron (Fe; ml/l; EPA 207. Rev 5, EPA 200.8).

Microbiological samples were taken once a month and analyses were done at the laboratory of the Institute of Public Health, Belgrade, Serbia, using standard methods (APHA AWWA WEF 1995, SMEWW 2010, SRPS EN ISO 9308–1: 2010). Macroinvertebrate samples were collected during high (May/June) and low water levels (September/October). Macroinvertebrates were collected from the river bottom using Van-Veen type of grab with sample area of 270 cm² (three replicates). The organisms were separated from the sediment with a sieve with mesh size 200 µm. The samples were preserved on site with 4% formaldehyde.

Biological material was processed in the Institute for Biological Research "Siniša Stanković", University of Belgrade. Identification was done mostly to species level or to the lowest possible taxonomic level using the following identification keys: Brinkhurst, Jamieson (1971), Hirvenoja (1973), Lellak (1980), Wiederholm (1983), Croft (1986), Uzunov *et al.* (1988), Hammond (1997), Timm (1999), Maschwitz, Cook (2000), Pfleger (2000), Epler (2001), Korniushin (2004) and Moller Pillot (2009).

Ecological analysis of community structure was done for each site. The number of taxa, ASPT (Average Score per Taxon), BMWP (Biological Monitoring Working Party score; Armitage *et al.* 1983), α-diversity index (H'; Shannon–Weaver 1949) and the percentage of the family Tubificidae (Oligochaeta) in macroinvertebrate communities were calculated. Saprobic index (S) was used to estimate the water quality class of the Sava River (Zelinka, Marvan 1961), using bioindicator valences of each taxon (Moog 2002). All biological indices were calculated using ASTERICS software package, version 3.1.1. (AQEM 2002).

The modified WPI (Milijašević *et al.* 2011) was used to estimate the water quality class.

The WPI is calculated as the sum of the ratio of the measured annual average value *Ai* and the stand-

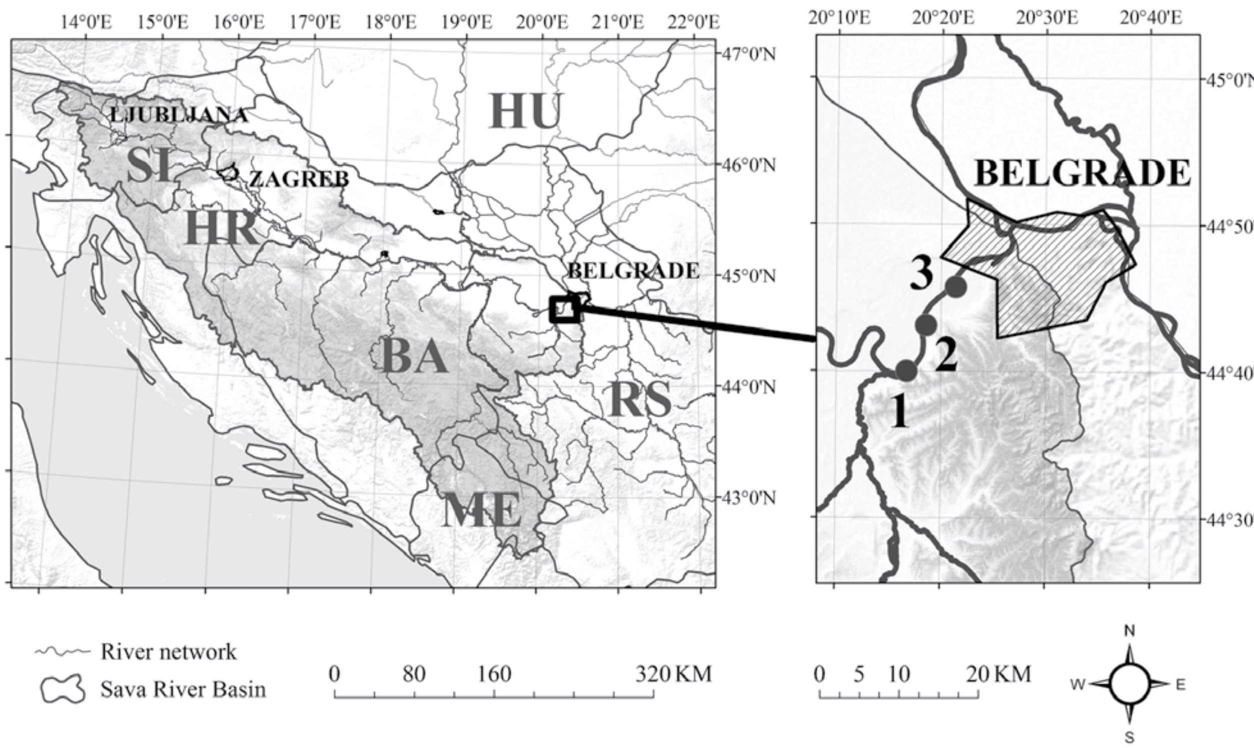

Fig. 1. Sampling sites on the Sava River

Table 1. Water quality classification based on the Water Pollution Index (WPI)

Water Quality Class		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	Heavily impure	> 6.0

ard threshold values T for each parameter, divided by the number of used parameters (n):

$$\mathrm{WPI} = \sum_{n=1}^{n} \frac{Ai}{T} \times \frac{1}{n}$$

The standard threshold values for all parameters are specific for each country, given as national legislative (Official Gazette RS 74/2011), which should minimise the bias caused by ecological and geographical differences.

The quality class according to WPI (Lyulko et al. 2000, Milijašević et al. 2011) are given in Table 1.

Results

Annual average values of physical, chemical, microbiological and biological parameters are shown in Table 2. The majority of the measured physical and chemical parameters were lower or near the threshold values for I water quality class, recommended for river type 1 (Official Gazette RS 74/2011; Table 2). Slightly higher values were recorded for DO, oxygen saturation, NO_3 and TOC. For these parameters according to the national legislation (Official Gazette RS 74/2011), water quality corresponded to class II. The number of coliform bacteria indicated III quality class (Table 2). The number of macroinvertebrate taxa was lower than the recommended for this type of river, which indicated III-IV water quality class. The values of Zelinka-Marvan saprobic index (S) indicated alpha–mesosaprobic to polysaprobic conditions, which is equivalent to III and IV water quality class. The Shannon–Wiener diversity index (H') indicated II-III water quality class while BMWP corresponded to V class of quality and ASPT indicated IV class. The percentage of Tubificidae in the macroinvertebrate communities was much greater than recommended, which indicated poor water quality (IV-V class).

The integrated water quality assessment using WPI for the five-year period is shown in Fig. 2. Based on our results, the Sava River had the poorest quality in year 2007 (IV class), with the WPI values 2.67 (Makiš), 2.39 (Duboko) and 2.26 (Zabran). In the period 2008–2010, the WPI indicated mainly III class with values ranging from 1.29 to 2.08 for Makiš, 1.07–1.83 for Duboko and 1.06–1.45 for Zabran. In 2011 water quality was assessed as II class, with WPI values 0.94 (Makiš), 0.90 (Duboko) and 0.84 (Zabran; Fig. 2).

Table 2. Annual average values of physical, chemical, microbiological and biological parameters at Sava River study sites. Threshold values (T) for I class are given as national legislative and water quality class for each measured parameter (I-V) (Official Gazette RS, 74/2011). M – Makiš, D – Duboko, Z – Zabran, in years 2007-2011

		2007			2008			2009			2010			2011		
Parameter	**T value**	**M**	**D**	**Z**	**M**	**D**	**Z**	**M**	**D**	**Z**	**M**	**D**	**Z**	**M**	**D**	**Z**
pH	8.5	8.09 I	8.09 I	8.10 I	8.11 I	8.13 I	8.15 I	8.04 I	8.06 I	8.05 I	8.03 I	8.05 I	8.02 I	8.14 I	8.18 I	8.15 I
Conductivity µS/cm	1000	361.88 I	353.75 I	352.50 I	356.88 I	358.75 I	356.25 I	352.67 I	340.00 I	340.00 I	359.38 I	357.50 I	358.75 I	383.13 I	385.00 I	382.50 I
Suspended matter mg/l	25	14.69 I	13.50 I	15.75 I	18.00 I	17.50 I	16.63 I	21.27 I	30.88 II	32.25 II	13.75 I	9.88 I	10.75 I	9.88 I	8.81 I	14.56 I
Dissolved oxygen mg/l	8.5	7.96 II	8.44 II	8.35 II	8.86 I	9.10 I	9.10 I	8.25 II	8.50 I	8.41 II	8.08 II	7.96 II	8.00 II	8.17 II	8.28 II	8.21 II
Oxygen saturation %	90	80.73 II	91.13 I	89.25 II	95.13 I	96.13 I	95.88 I	89.93 II	90.00 I	89.63 II	84.56 II	83.50 II	83.38 II	87.31 II	88.13 II	87.00 II
BOD_5 mg/l	2	1.64 I	1.84 I	1.39 I	1.67 I	3.79 II	1.41 I	1.16 I	1.29 I	0.99 I	1.33 I	0.87 I	0.83 I	1.06 I	0.83 I	0.67 I
COD_{Mn} mg/l	10	9.69 I	9.10 I	9.31 I	9.41 I	7.96 I	9.58 I	9.37 I	10.65 II	10.68 II	2.76 I	2.53 I	2.61 I	1.97 I	1.93 I	1.74 I
Ammonium ion mg/l	0.1	0.109 II	0.081 I	0.076 I	0.108 II	0.077 I	0.092 I	0.083 I	0.068 I	0.083 I	0.122 II	0.121 II	0.146 II	0.118 II	0.083 I	0.123 II
Nitrites mg/l	0.01	0.017 II	0.015 II	0.014 II	0.015 II	0.016 II	0.016 II	0.013 II	0.013 II	0.012 II	0.014 II	0.013 II	0.013 II	0.016 II	0.017 II	0.016 II
Nitrates mg/l	1	1.156 II	1.038 II	1.038 II	0.950 I	0.988 I	1.000 I	1.068 II	1.094 II	1.129 II	1.851 II	1.093 II	1.116 II	0.983 I	0.975 I	0.963 I
Organic carbon mg/l	2	2.59 II	2.43 II	2.42 II	2.36 II	2.13 II	2.13 II	2.21 II	2.33 II	2.11 II	2.88 II	2.83 II	2.82 II	2.08 II	2.02 II	1.86 I
Chlorides mg/l	50	12.89 I	13.25 I	12.58 I	10.65 I	13.28 I	14.26 I	12.51 I	11.98 I	12.50 I	13.01 I	11.75 I	11.78 I	17.37 I	16.63 I	17.15 I
Zinc mg/l	0.5	0.0321 I	0.0413 I	0.0423 I	0.0135 I	0.0153 I	0.0153 I	0.0106 I	0.0115 I	0.0103 I	0.0086 I	0.0061 I	0.0046 I	0.0101 I	0.0055 I	0.0083 I
Copper mg/l	0.112	0.0043 I	0.0108 I	0.0075 I	0.0027 I	0.0028 I	0.0045 I	0.0028 I	0.0030 I	0.0028 I	0.0029 I	0.0019 I	0.0019 I	0.0034 I	0.0019 I	0.0031 I
Arsenic mg/l	0.005	0.0013 I	0.0011 I	0.0011 I	0.0015 I	0.0015 I	0.0010 I	0.0010 I	0.0013 I	0.0011 I	0.0012 I	0.0010 I	0.0013 I	0.0016 I	0.0015 I	0.0015 I
Iron mg/l	0.2	0.0264 I	0.0266 I	0.0270 I	0.0306 I	0.0374 I	0.0301 I	0.1017 I	0.1125 I	0.0773 I	0.4144 II	0.3103 II	0.3123 II	0.4279 II	0.1510 I	0.1130 I
Total phosphates mg/l	0.05	0.0634 II	0.0628 II	0.0588 II	0.0614 II	0.0579 II	0.0591 II	0.0555 II	0.0525 II	0.0475 I	0.0498 I	0.0524 II	0.0523 II	0.0498 I	0.0434 I	0.0454 I
Number of coliform	5000	193125 III	167375 III	154000 III	117863 III	48775 II	53475 II	155455 III	97433 II	65000 II	23409 II	12950 II	8053 II	9640 II	10325 II	4663 II
Number of taxa	17	9.0 III	6.0 III	9.5 III	9.5 III	5.5 IV	8.5 IV	6.0 IV	6.5 IV	10.0 II	6.5 IV	9.0 III	10.0 II	8.0 IV	6.5 IV	8.0 IV
Saprobic index	2.1	3.28 V	3.10 IV	2.90 III	2.95 IV	3.09 IV	3.24 V	2.53 II	2.85 III	3.03 IV	2.75 III	2.74 III	3.03 IV	2.73 III	2.67 III	2.67 III
BMWP score	50	13.0 IV	4.5 V	6.0 V	12.0 IV	6.5 V	10.0 IV	5.0 V	6.5 V	8.5 V	3.5 V	7.0 V	8.5 V	9.0 V	10.5 IV	6.0 V
ASPT score	5	3.00 III	1.75 V	2.00 IV	3.25 III	2.42 IV	2.88 IV	2.00 IV	2.50 IV	2.50 IV	1.50 V	2.67 IV	3.58 III	2.50 IV	3.00 III	2.25 IV
Diversity index	2.2	0.976 IV	1.241 III	1.695 II	1.493 III	1.470 III	1.399 III	1.480 III	1.627 II	1.981 II	1.373 III	1.870 II	1.863 II	1.595 II	1.719 II	1.854 II
% of Tubificidae	10	92.01 V	87.03 V	83.89 V	45.37 IV	81.65 V	84.71 V	40.80 IV	86.71 V	54.64 IV	93.80 V	72.79 V	74.66 V	44.02 IV	52.62 IV	48.01 IV

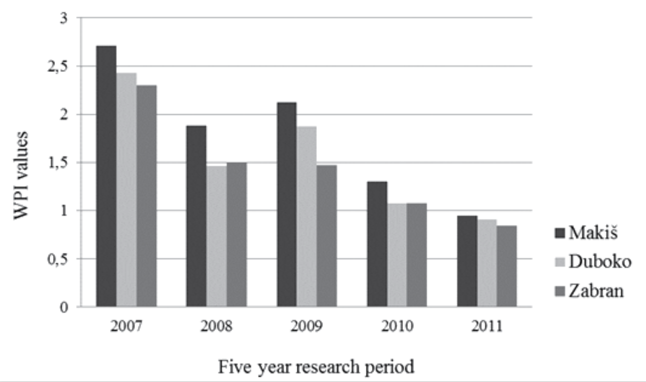

Fig. 2. Water quality class according to WPI at three localities of the Sava River

Discussion

In this paper, we discuss the possibility of combining the results of water quality/status assessment by different quality elements in a single value. Physical, chemical, microbiological and biological parameters are used to evaluate the status of the Sava River in Belgrade area. This river stretch is appropriate for testing the assessment of the lotic systems effectiveness, since the area is under the influence of different stressors, including organic and nutrient pollution, influence of industry and hydromorphological degradation (Simić *et al.* 2015).

Physical and chemical analyses do not show considerable deviations from I and II quality class according to the national regulation (Official Gazette RS 74/2011). Minor organic pollution was detected. On the other hand, high number of coliform bacteria is the consequence of pollution with waste waters (Kolarević *et al.* 2011) since Belgrade does not have a system for treating municipal waste waters (Živadinović et al. 2010). Also, the results of assessment based on BQE suggest worse ecological status. According to the biological parameters, water quality of the Sava River varied in wide range from III to V quality class. These results are consistent with the fact that the Sava River in Belgrade area is primarily under significant organic pollution pressure (Paunović *et al.* 2012, Ogrinc *et al.* 2015). According to the WPI values, the studied stretch in Belgrade region could be assessed as polluted in 2007, moderately polluted for the period 2008-2010, and slightly polluted in 2011. Considering the WPI results, the Sava River shows tendency of overall water quality improvement (Fig. 2). The WPI reflected combined results of single assessments by physical, chemical, microbiological and biological water status assessment and provided more reliable evaluation of the status of the water body. As described above, single assessment based on physical and chemical parameters indicated better status than expected, having in mind the known pressures occurred regularly in investigated stretch of the Sava River (Ogrinc et al. 2015), while microbiological and biological parameters provided more realistic status assessment results. This clearly underlines the need for further calibration of threshold values for the ecological status class boundaries for physical and chemical parameters, and confirms the necessity of multimetric approach in water monitoring, including biological and microbiological metrics.

Biological parameters are essential assessment tool since they can represent long-term influence of pollution (Dorn 2007). BQE are mandatory to be used in assessment of the ecological status according to the requirements of the WFD and the national legislation of all EU countries and a considerable number of non-EU countries (e.g. Serbia, Bosnia and Herzegovina, etc.).

Our results show that the WPI is useful tool for integrating the assessments results based on different quality elements; adding biological quality parameters can improve the confidence of the assessment. There is a need for further development of the WPI and the index should be tested for different water body types to verify its applicability. However, our study is based on quantitative sampling approach only, which could lead to underestimation of the species richness, but can also overestimate the influence of stressors (Csanyi, Paunovic 2006, Csanyi et al. 2014) and thus could reflect worse ecological status than the actual state. The index should also be tested for other BQE and different sampling methods. This approach should be harmonised with other methods of assessment of water body status, which were developed based on the requirements of the WFD. Hence, the index should include (river) type specific threshold values, as well as stressor specific metrics (relevant for hydromorphological degradation, organic, hazardous and other chemical pollution). Any future use of the WPI should encompass the use of final score presented through a 5-class assessment result, as required by the WFD. Furthermore, for the purpose of harmonisation, the WPI values should range from 0 to 1, so that the Index of Ecological Status (ecological potential in the case of heavily modified and artificial water bodies) could be expressed as a single value, comparable with other assessment systems provided across Europe.

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