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Water Quality Assessment Based on Combined Multi-Criteria Decision-Making Method with Index Method

Ivana I. Mladenović-Ranisavljević[1] · Lj. Takić[1] ·
Đ. Nikolić[2]

Abstract This work presents combined approach to water quality assessment based on both Water Quality Indices (WQI) and Multi-Criteria Decision-Making (MCDM) methods. Using weights from the official WQI calculation algorithm, the model for MCDM was formed and presented on the case of the Danube River water quality in Serbia. By applying PROMETHEE method, locations of potential environmental risk were determined and ranked according to the quality of water. Using its visual modeling option GAIA, the most dominant variables that affect the quality of water at certain locations were identified as polluting parameters (suspended matter, BOD-5, total N, NH4-N and PO4-P). Concentrations of identified pollutants were compared with limits of both EU and national recommendations so the actual water quality of the river was determined. The results showed that although WQI analysis indicated good and very good water quality, extension with MCDM methods revealed that there is a significant excess in values of PO4-P and *E.coli* at almost every location on the course of the river, as well as in values of total N and NH4-N. Proposed combined approach could serve to engineers and decision makers involved in water quality management in creating more detailed reports on water quality while facilitating the process of decision-making in the choice of selection of particular locations with critical water quality, where appropriate measures for remediation of pollution should be taken.

Keywords Water quality index · Multi-criteria decision-making · The Danube River · Dominant polluting parameters

✉ Ivana I. Mladenović-Ranisavljević
   282ivana@gmail.com

[1] Faculty of Technology, University of Niš, Bulevar oslobođenja 124, Leskovac 16000, Serbia

[2] Technical Faculty in Bor, University of Belgrade, VJ 12, Bor 19210, Serbia

1 Introduction

Many researchers point out that pollution, sustainability and limitation of water resources represent the actual problems of today (Ene et al. 2010; Gatica et al. 2012; Griffiths et al. 2017; Su et al. 2017; Khan 2011; Shi et al. 2017). The quality of the surface waters, as a function of biological, physical and chemical parameters, depends on natural and anthropogenic factors such as atmospheric conditions and soil erosion as well as industrial and agricultural activities, respectively (Khatri and Tyagi 2015; Voza et al. 2015). Due to a large number of different variables that define the water quality, it is quite difficult to identify and express it easily. The method of Water quality indices (WQI) solves this problem by summarizing numerous parameters into a unique index value (Cude 2001). A number of water quality analysis presented in literature are based on calculating WQI in order to observe changes in the quality of the given water body (Debels et al. 2012; Rocha et al. 2015; Sanchez et al. 2007; Sener et al. 2017) as well as to assess its suitability for water supply purposes (Akter et al. 2016; Ochuko et al. 2014). Moreover, the Agency for Environmental Protection of the Republic of Serbia also uses WQI indicator for informing on the state of quality of water resources (SEPA 2004).

Still, Abbasi and Abbasi (2012) explained why the indexing methods do not provide precise information on the actual state of the quality of watercourses. The main reason is that data aggregation can either camouflage or exaggerate short-term problems of water quality. Namely, a good WQI score on a certain measuring location does not necessarily mean that the water quality is constantly at a satisfactory level, but indicates that the water quality is not "chronically" bad in the observed time period (Parparov et al. 2006; Swamee and Tyagi 2000). Therefore, in determining detail interrelations between the quality parameters and measuring locations, the evaluation of water quality needed to be expanded with Multi-criteria decision-making (MCDM) analysis.

Application of MCDM in water quality analysis provided remarkable results (Mladenović-Ranisavljević 2012; Mutikanga et al. 2011; Raju et al. 2000; Talukder et al. 2017). Recently, evaluation of sediment quality of the Danube River and Sava River in Serbia was performed using MCDM methods of PROMETHEE and GAIA which provided valuable information to the sediment quality assessment (Crnković et al. 2016). Salehi et al. (2017) developed model for rehabilitation planning of water networks using fuzzy TOPSIS method of MCDM, adjusting the criteria based on the local conditions and weights assigned based on the group decision-making of experts. Nevertheless, some of the researchers identified the need for applying both MCDM and index methods. Sutadian et al. (2017) used AHP method of MCDM analysis to determine weights and parameters to be used in Indonesian WQI index. Also, Lee et al. (2012) used MCDM to optimize set of WQI indicators along with sensor devices for online monitoring of water quality to improve it. Yousefi et al. (2018) used TOPSIS, CP and OWA methods of MCDM for checking validity and conflicting issues of WQI classes and concluded that it is possible to take away contradictions in WQI calculation using MCDM models.

But none of the former works has developed such hybrid MCDM-WQI approach in the assessment of water quality, based on the exact quality weights as used in the official WQI for the public reporting on the state of water quality, as presented in current investigation. Presented approach provided detailed evaluation of water quality, applicable to any surface water. The use of PROMETHEE (*Preference Ranking Organization METHod*

for *Enrichment Evaluation*) and GAIA (*Geometrical Analysis for Interactive Assistance*) methods in current investigation rather than other MCDM methods was chosen because of much easier way of problem settling by quantifying the quality variables, for instance, and processing large data in a light, understandable manner (Behzadian et al. 2010; Leoneti 2016; Nikolić et al. 2010). Application of PROMETHEE and GAIA methods involves defining the appropriate functions of preferences and assigning the weight significance to each individual criterion. Determining the weights of significance is a very important step in all MCDM methods, including PROMETHEE, where decision maker (DM) must be sufficiently informed and objective in order to adequately assign weights to each criterion (Macharis et al. 2004). So, weights of the WQI index adopted by the Serbian Environmental Protection Agency, predetermined and explained in detail by Veljković (2013), were used as criteria weights in MCDM model of the current study.

This investigation included ten water quality parameters monitored monthly at ten measuring locations on the Danube River in Serbia, for the year of 2014. The concept of research includes several important steps. Firstly, an overall assessment of the water quality of the river was done using WQI index, initially calculated. Afterwards, the analysis of water quality is extended with MCDM method of PROMETHEE along with its visual modeling method GAIA that identifies significant criteria (parameters) and its interdependence with the alternatives (locations). Values of the identified variables were then compared with the permissible limits for human consumption prescribed by both European and national standards and conclusions were made.

2 Methodology

2.1 WQI Method

WQI is obtained by aggregating n quality parameters into one value that represents quality indicator of the observed water body (Walsh and Wheeler 2012). Each parameter, depending on the measured value (p_i) gets its corresponding qualitative indicator (q_i) such that $q_i = Q_i (p_i)$, where Q_i represents quality transformation curve of the ith parameter. Transformation quality curves with limitations of range for each parameter (e.g. for BOD-5 on a scale of 0–100 for measured values of 0–30 mg/L) were obtained based on the results of extensive research of the water quality experts presented in detail in Brown et al. (1970). Weighting coefficient (w_i) represents the importance of ith parameter in threatening the water quality, determined by the water quality experts (SDD 1976; Veljković 2013). The basic principle for calculating WQI is given in the Eq. (1). Based on a described WQI method, official government agency in Serbia has developed on-line software application for calculating water quality (SEPA 2004), available for the public use and checking of the results.

$$WQI = \sum_{i=1}^{n} (q_i w_i) \tag{1}$$

The obtained index value is a number that is in the range between 0 and 100, depending on the scored points of individual parameters, where the sum of 100 shows maximum quality. In the case of missing data on certain parameter, the value of WQI is corrected through

multiplication of the index value by reciprocal value of the sum of arithmetically measured weights of the available parameters.

2.2 PROMETHEE Method

Mathematically speaking, if a finite set of n available actions (alternatives) $A = \{a,b, ...,n\}$ is to be ranked based on a set of p criteria marked as $K = \{k_1, k_2, ..., k_p\}$, then $Max \{k_1 (a), k_2 (a),... k_p (a) \mid a \in A\}$ needs to be found (Ishizaka and Nemery 2013).

The basic principle of the process of ranking within the PROMETHEE method consists in comparing paired alternatives (a, b) on criterion k_j, calculating a deviation between estimates of the two options within each defined criteria as $d_j(a,b) = k_j(a)-k_j(b)$. The greater the deviation, the greater the value of the preferences will be. In the case of a large number of criteria, all pairs of the existing alternatives on each criterion are considered individually by defining function of preference $P_j(a,b)$ as preference of alternative a over the alternative b. Its value ranges from 0 to 1, i.e. $0 \leq P_j(a,b) \leq 1$, where $P_j(a,b) = 0$ refers to no preference and $P_j(a,b) = 1$ to strict preference (a totally dominates over b),while $P_j(a,b) \neq P_j(b,a)$. Brans et al. (1984) cited six types of possible functions of preferences $P_j(a,b)$ as: basic, the U-shaped, V-shaped, the level form, linear and Gaussian function. Each one is described with preference threshold (P) that defines the minimum deviation significant for decision-making and indifference threshold (Q) showing the maximum deviation that is irrelevant to the decision-making process.

After having each criterion defined by its type, the next step is calculation of the so-called "index of preferences" (IP) shown in Eq. (2) while taking into account each pair of alternatives from the set A along with their weights t_j assigned to each k_j criterion and preference function $P_j(a,b)$. Sum of all weights is always 1.

$$\forall a, b \in A : IP(a,b) = \sum_{j=1}^{p} t_j P_j(a,b) \qquad \left(\sum_{j=1}^{p} t_j = 1 \right) \tag{2}$$

The final step is obtaining positive (Φ^+) and negative preference flow (Φ^-) for each alternative from the set A, with respect to the criteria weights. Φ^+ indicates how much a certain alternative a prevails over the other ones, and it is given by the Eq. (3). Accordingly, the higher the value of $\Phi^+(a)$, the greater the significance of the alternative will be.

$$\phi^+(a) = \frac{1}{n-1} \sum_{b \in A, b \neq a} IP(a,b) \tag{3}$$

Φ^- given in Eq. (4) indicates how much a certain alternative a is preferred by other alternatives, so when the value of $\Phi^-(a)$ is lower, the alternative is more dominant.

$$\phi^-(a) = \frac{1}{n-1} \sum_{b \in A, b \neq a} IP(b,a) \tag{4}$$

Calculation of total net flow (Φ) as $\Phi(a) = \Phi^+(a)-\Phi^-(a)$ gives the complete ranking of alternatives such that the alternative with the highest value of Φ is ranked as the best one (Brans et al. 1984).

2.3 GAIA Visual Modeling Method

GAIA visualization modeling provides the decision maker with necessary information about conflicting characters of criteria and their weight impact on the final score in PROMETHEE rankings (Nemery et al. 2011). It is based on Principal Component Analysis (PCA) and defined by vectors derived from the matrix of covariance, formed through PCA analysis (Nemery et al. 2012). The axes u and v of the GAIA plane are assistive axes that divide the space to present the strengths of the alternatives and criterions better. The position of criteria, marked with squares in the plane, shows the strength of the impact of the criteria, while the accordance between certain criteria is defined with approximately the same direction of axes of these criteria. Thus, for a defined scenario it is possible to determine the accordance between the observed parameters. Also, position of the alternatives, represented by triangles, determines the strength or weakness of an alternative towards the criteria. If it is closer to the orientation of the criterion axis, therefore, a single alternative is better on this exact criterion (Ishizaka and Nemery 2013; Nikolić et al. 2010). The amount of information stored within the given GAIA model is in most literature cases up above 60%, and in some cases beyond 80% (Brans and Mareschal 2005).

By means of the general method, as particularly important factors of a potential environmental risk that affect the quality of the water, certain criteria (relevant and dominant parameters) can be set aside.

3 Case Study

The Danube River is the second longest river in Europe that passes through ten different countries and receives water from 19 countries located in its basin (ICPDR 2005). Out of a total 2850 km in length, 588 km runs through Serbia (Fig. 1). The Danube water in Serbia is generally used for water supply, both industrial and domestic, as well as for electricity generation, irrigation, transportation, etc.

For the purpose of this research, data collection from 10 measuring stations (S1 - S10) on the Danube River shown in Fig. 1 was used. Ten water quality parameters used in Serbian WQI indicator were observed monthly at these sites, namely temperature (T), electrical conductivity (EC), pH, oxygen saturation (OS), biochemical oxygen demand (BOD-5), suspended matter (SM), *E.coli*, total oxides of nitrogen (N), orthophosphate (PO_4-P) and ammonium ion (NH_4-N). Water quality parameters were sampled and determined according to standard prescribed procedures and methods (Report 2015) as shown in Table 1.

WQI index used in Serbia for evaluation and classification of surface water quality uses the original WQI methodology presented above. According to the points scored, it puts water quality into the following categories: excellent (100–90), very good (89–84), good (83–72), poor (71–39) and very poor (38–0) water quality. There are special uses for each category defined, namely, excellent-for water supply, food industry and cultivating certain species; very good and good water quality-for swimming and recreation, water sports, cultivating certain species or, after modern purification treatments, for water supply and food industry; poor-for irrigation and industries other than food; very poor-use only after purification procedures (SEPA 2004). These categories of water quality are also illustrated with colors on the maps of
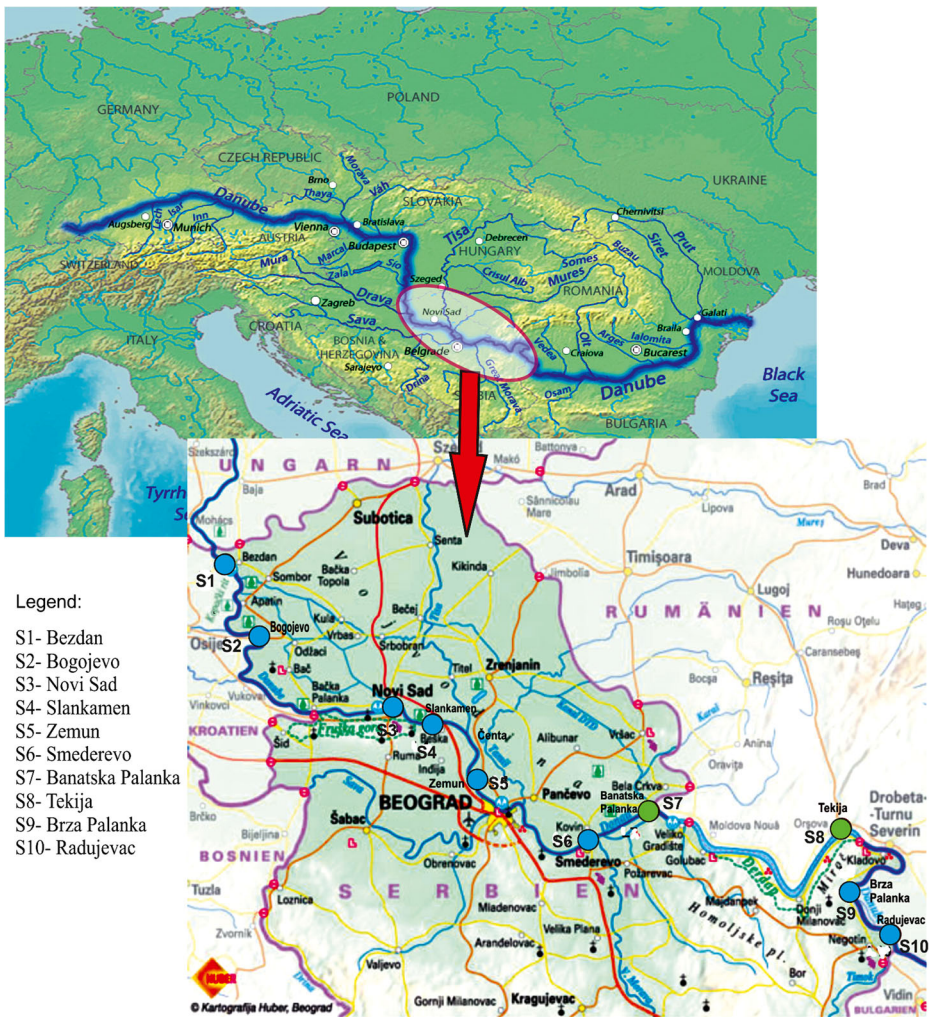
Fig. 1 Map of the Danube River Basin with marked measuring sites on the Danube River in Serbia

watercourses as: dark blue (excellent), light blue (very good), green (good), yellow (poor) and red (very poor). In case of unavailability of data, white color is sometimes used.

Weights of the Serbian WQI, further used in creating MCDM model, are presented in Table 1, where parameter with the most significant share in obtaining WQI value is OS ($w_i = 0.18$) while T is with the lowest share ($w_i = 0.05$). The sum of all weights together is 1.

4 Results and Discussion

4.1 WQI Analysis

Values of ten water quality parameters of the Danube, gathered monthly from ten measuring sites along the Danube River in Serbia, were averaged on annual basis for the year of 2014.

Table 1 Calculated values of the water quality parameters at measuring sites

Parameters		T	EC	pH	OS	BOD-5	E. coli	SM	N	PO₄-P	NH₄-N	WQI
Unit		°C	µS/cm	–	%	mg/L	per 100 mL	mg/L	mg/L	mg/L	mg/L	–
Method		SRPS H.Z1. 106: 1970	EPA Method 120.1	SRPS H. Z1.111:1987	SRPS H. Z1.135:1970	EPA 360.2	48 h after the incubation at 37 °C	SRPS H. Z1. 160:1987	DIN EN ISO 11905–2	APHA AWWA WEF 4500-P	SRPS ISO 7150-1:1992	$\Sigma q_i w_i$
Weight (w_i)		0.05	0.06	0.09	0.18	0.15	0.12	0.07	0.08	0.08	0.12	$\Sigma w_i = 1.00$
Stability intervals of weights	min	0.0423	0.0000	0.0000	0.1787	0.1283	0.1189	0.0581	0.0793	0.0583	0.1179	
	max	0.1007	0.0850	Infinity	0.2068	0.1506	0.1730	0.0840	0.1034	0.0805	0.1289	
Locations												
S1		12.88	413.66	8.3	99.91	2.10	3440	26.58	1.663	0.037	0.02	85
S2		15.49	392.09	8.2	98.54	1.85	*	23.18	1.440	0.038	0.03	88
S3		13.70	395.75	8.1	89.25	2.20	2600	24.83	1.590	0.050	0.06	84
S4		15.19	380.00	8.2	92.00	2.06	*	28.18	1.420	0.042	0.03	85
S5		14.69	399.16	8.1	86.00	1.54	*	18.16	1.230	0.053	0.17	84
S6		18.38	385.4	8.0	86.16	1.30	*	20.58	0.930	0.057	0.13	85
S7		15.90	373.63	8.1	78.81	1.27	3155.45	27.00	1.150	0.045	0.11	83
S8		14.88	383.33	8.0	86.91	2.11	9540	18.33	0.840	0.047	0.10	82
S9		14.93	380.10	8.1	87.08	1.85	515	17.25	0.710	0.042	0.11	86
S10		15.18	387.00	8.0	91.50	1.91	629.6	26.41	0.740	0.093	0.09	86

Legend: * stands for missing data

WQI was then calculated on each location (Table 1) and colored on the map (Fig.1) according to the methodology classification described.

Obtained WQI values show that location with the best water quality is S2 (with 88 index points scored), while S8 is the location with the poorest water quality scored by 82 index points. The quality of the Danube River in Serbia ranged from 82 to 88 index points, which corresponds to descriptive indicators of good and very good water quality referring to possible use for swimming and water sports, cultivating certain species and, after modern treatments, for water supply and food industry.

WQI values were also calculated on monthly basis, at entering (S1) and exiting profile (S10) of the river's flow in Serbia for the observed period and shown within the line chart (Fig. 2). It is noticeable that the water quality of the Danube on both measuring points is better in the winter months (January, February, March, November and December) than in summer period (May, June, July, August and September), as expected due to the impact of increased water temperature. This is particularly apparent in the monthly value of index in June (WQI = 76) when the water temperature measured at location S10 was in the range from 21.7 to 29.2 °C due to which oxygen saturation of water (OS) had the lowest value of 79%, while BOD-5 had one of the highest individual values of 2.6 mg/L. Consequently, the concentration of NH_4-N was increased up to 0.24 mg/L, which all together contributed to the unfavorable WQI value.
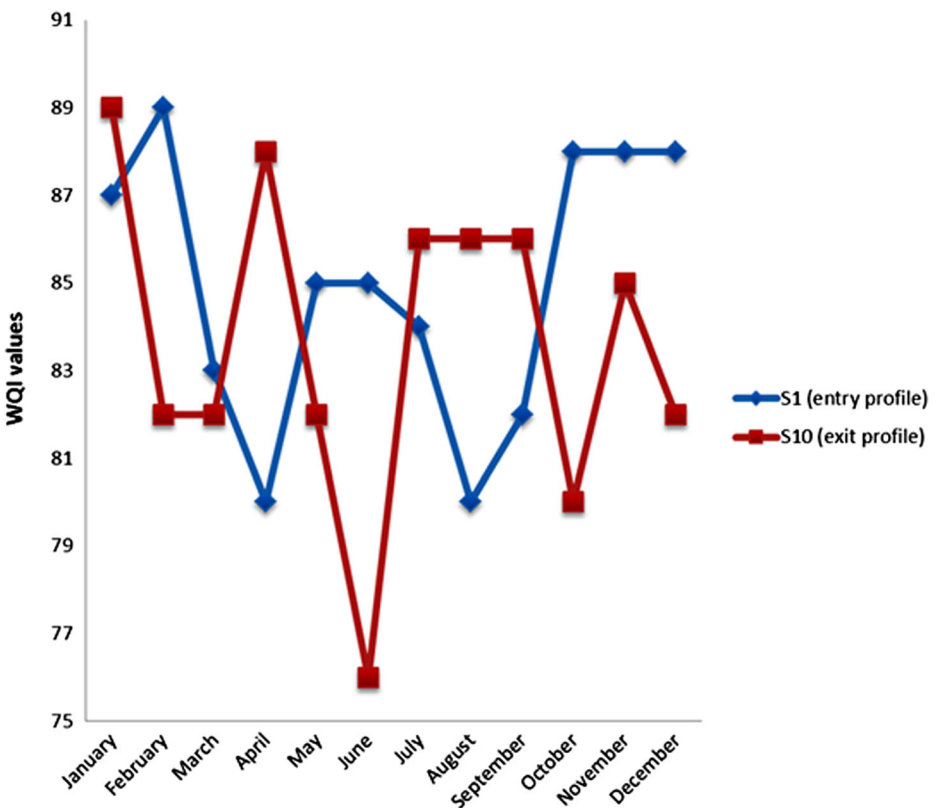

Fig. 2 Changes of WQI values on a monthly basis

4.2 PROMETHEE Method Application

Scenario for the evaluation of alternatives (locations) according to the selected criteria (quality parameters) using PROMETHEE method was created having in mind some of the characteristics of the surface water parameters. As shown in Fig. 2, saturation of water with oxygen significantly affects the water quality. Low concentrations of dissolved oxygen disturb the balance of aquatic ecosystem and can reflect in severe dying of aquatic species, unpleasant odors and other inconveniences, so OS content in defining the scenario should be maximized. The other nine parameters need to be present in water with as low concentrations as possible, thus they should be minimized. Since parameters are quantitative in nature, linear preference function was set as preference function for all of the criteria. Preference threshold *(P)* is set to 30%, while indifference threshold *(Q)* was adjusted to 5%.

When creating MCDM models, assigning the appropriate weight to each criterion represents a real challenge for decision maker (DM). It almost always comes with a dose of uncertainty. Therefore, an important task concerning sensitivity analysis is to be done i.e. the assigned weights should be observed in relation to their stability intervals. If these intervals are stable and reasonable, then the assigned weights are chosen well (Nemery et al. 2011). This is particularly important in our investigation because the aim was to create MCDM scenario in consistency with the weights used in the official WQI for the public reporting on the state of the water quality in Serbia. Weights, along with their stability intervals, are shown in Table 1. Accordingly, the final order of ranking remains the same within the given intervals of weights which proves the stability of the presented model.

Based on the calculated values of the water quality parameters and defined weights (see Table 1), the values of positive *(Φ+)*, negative *(Φ-)* and net flows *(Φ)* were obtained, together with the ranking results, as shown in Table 2.

The results show that the least polluted site is location S9 (Φ = 0.1242), while the most polluted one is location S3 (Φ = −0.1040). Such ranking results show some differences compared to the results obtained within WQI analysis, so the reasons for that need to be investigated in more detailed analysis of GAIA plane.

4.3 Results Obtained within the GAIA Plane

The amount of information saved within the given model is at the acceptable level of 72.66% so it is justifiable to use GAIA visual modeling tool. The analysis of GAIA flat identifies the most important variables that affect the quality of water (Fig. 3).

Table 2 Ranking of locations based on the preference flows

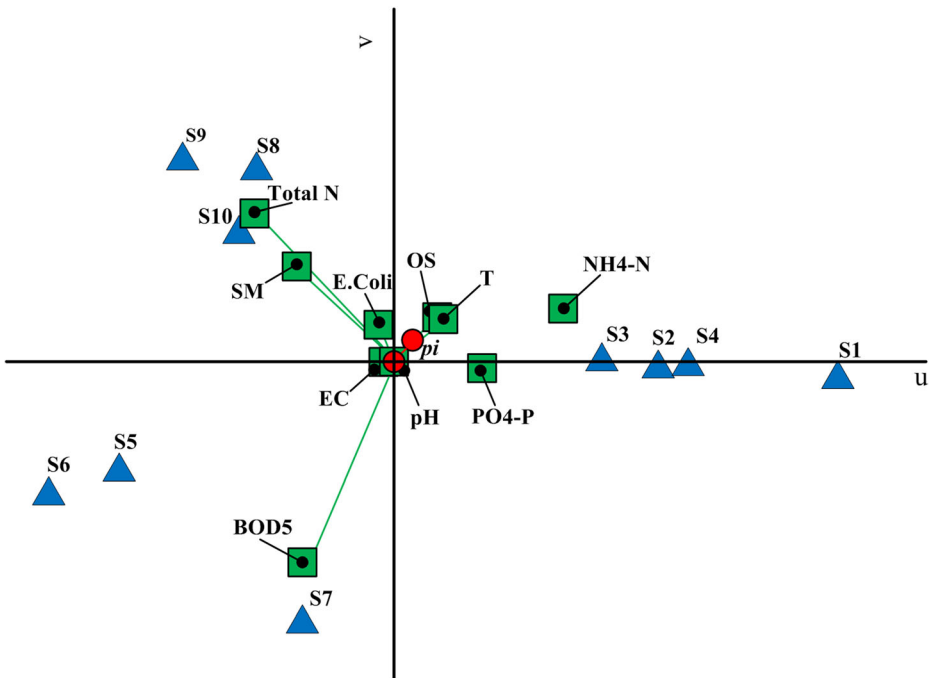| Locations	Φ^+	Φ^-	Φ	Ranking
S1	0.2599	0.2019	0.0581	3
S2	0.2325	0.1177	0.1148	2
S3	0.1470	0.2510	−0.1040	10
S4	0.1479	0.1574	−0.0095	5
S5	0.1682	0.2222	−0.0540	8
S6	0.2227	0.2030	0.0197	4
S7	0.2104	0.2489	−0.0384	7
S8	0.1500	0.2228	−0.0728	9
S9	0.2493	0.1252	0.1242	1
S10	0.1854	0.2233	−0.0379	6

Fig. 3 GAIA plane for the defined Scenario

Parameters located in the very beginning of the GAIA coordinate plane such as pH and EC are neutral criteria with minimum impact on the ranking. Decision stick *pi* defines a compromising solution in accordance with the given weights of the criteria, so this stick is a kind of a pointer on a track to the best solution. Locations S9, S10 and S8 are the closest ones to the decision stick, which is why they are good by a majority of criteria and clearly with the lowest concentrations of total N, SM and *E. coli*, which leads to a good water quality. Locations that are opposite to *pi*, such as S7, S5 and S6, are not good according to criteria of OS, T, NH_4-N and PO_4-P. However, these locations are good as seen from the aspect of BOD-5 criterion, especially S7 positioned directly towards BOD-5 criterion line, pointing to the lowest concentration of this parameter. Locations S1, S2, S3 and S4 are locations with the lowest values of NH_4-N, but with elevated values of parameters located opposite to them, such as BOD-5, total N and SM.

4.4 Comparison with the Limit Values of EU Recommendations and Serbian Standards

The analysis of GAIA flat identified the most dominant variables (SM, BOD-5, total N, NH_4-N and PO_4-P) that affect the quality of water at different locations. In order to determine exceeding of parameters' values, comparison with the limit values of EU Recommendations (EU Directive 1975) and Serbian standards (Regulation 2012) was conducted (Table 3). In addition, *E.coli* and OS were also observed herein due to the given relevance in establishing preference's weights of scenario, i.e. their closeness to the decision stick.

An increase in the average annual values of SM is observed compared to the values prescribed by EU and Serbian standards (25 mg/L) at locations S1, S4, S7 and S10

Table 3 Limit values according to the EU and national standards

Parameters	OS			BOD-5			SM			N			PO4-P			NH4-N			E.coli		
Unit	%			mg/L			mg/L			mg/L			mg/L			mg/L			per 100 mL		
Value	min	average	max	min	average	max	min	average	max	min	average	max	min	average	max	min	average	max	min	average	max
S1	91	99.91	128	1.0	2.10	4.7	10	26.58	43	1.081	1.663	2.574	<0.01	0.037	0.059	<0.02	0.02	0.04	500	3440	12,000
S2	88	98.54	113	1.0	1.85	3.3	8	23.18	42	1.012	1.440	2.245	<0.01	0.038	0.063	<0.02	0.03	0.06	*	*	*
S3	79	89.25	98	1.0	2.20	3.1	8	24.83	41	0.954	1.590	2.475	0.015	0.050	0.067	0.04	0.06	0.08	1400	2600	4000
S4	85	92.00	102	1.0	2.06	7.0	6	28.18	67	1.011	1.420	2.304	<0.01	0.042	0.059	<0.02	0.03	0.05	*	*	*
S5	77	86.00	94	1.0	1.54	2.5	4	18.16	34	0.213	1.230	2.353	0.026	0.053	0.086	0.09	0.17	0.25	*	*	*
S6	75	86.16	102	0.7	1.30	2.5	3	20.58	80	0.216	0.930	1.561	0.014	0.057	0.104	0.03	0.13	0.23	*	*	*
S7	78	78.81	93	1.0	1.27	2.0	13	27.00	57	0.852	1.150	1.644	0.015	0.045	0.067	0.06	0.11	0.19	110	3155.45	10,000
S8	70	86.91	111	1.2	2.11	3.2	2	18.33	104	0.309	0.840	1.318	0.025	0.047	0.079	0.03	0.10	0.18	130	9540	18,950
S9	71	87.08	98	1.0	1.85	3.0	<1	17.25	67	0.206	0.710	1.023	0.018	0.042	0.077	0.03	0.11	0.22	110	515	920
S10	79	91.50	109	1.2	1.91	3.1	<1	26.41	84	0.410	0.740	1.127	0.026	0.093	0.196	<0.02	0.09	0.24	49	629.6	920
Limit values according to EU Recommendations																					
A1	>70			<3			25			1			*			0.05			20		
A2	>50			<5			—			2			*			1			2000		
A3	>30			<7			—			3			*			2			20,000		
Limit values according to Serbian Regulations																					
Class I	90–110			2			25			1			0.02			0.1			100		
Class II	70–90			5			25			2			0.1			0.3			1000		
Class III	50–70			7			—			8			0.2			0.6			10,000		
Class IV	30–50			25			—			15			0.5			1.5			100,000		
Class V	<30			>25			—			>15			>0.5			>1.5			>100,000		

Legend: * stands for missing data

indicating that the Danube water quality did not meet the required water quality at these locations according to both European and national standards, even though there were some quite low monthly values recorded (S9 and S10). BOD-5, as a very good indicator of negative influence of partially processed or unprocessed waste waters from agglomerations, industry and agriculture on the water recipients, indicates that the water quality at locations S1, S3, S4 and S8 is with higher organic matter pollution according to Serbian standards (>2 mg/ L) but still within the range of A1 category of European directive. Monthly excess in value of this parameter that is on the verge of A3 category of EU directive (7 mg/ L) has been recorded at the site S4, to which the analysis of GAIA flat previously indicated. There is also an evident excess in the average annual values of total N according to the limit values defined within both EU and Serbian regulations (1 mg/L) at most of the sites on the Danube River (S1-S5 including S7). Maximum monthly values are in the extent of values defined for the A3 category of EU directive. Elevated levels of total N indicate pollution caused by chemical industry, sewage, fertilizers and agricultural runoff. It can affect the growth and decay of plants and promote bacterial decomposition, all of which may reduce the amount of oxygen available in the water. Average values of PO_4-P exceed the limit value for the class I of the Serbian regulations (0.02 mg/L) at every single site along the course of the river (S1-S10). Increased concentration of PO_4-P drives up to eutrophication, which eventually destroys the natural aquatic eco-system, its structure and leads to the biodiversity loss. The most significant source of phosphorus pollution comes from municipal and industrial wastewater treatments. NH_4-N intensely deviates from the threshold values of A1 category and also from the first class of the national permissible values at locations S5 to S9. Ammonium is frequently derived in water from anthropogenic sources, such as fertilizers or leakage of waste water.

$E.coli$ in water originates from sanitary contamination of the river at locations S1, S3, S7 and S8 ranking it into A3 category and class II of water quality, but the values are significantly lower toward the exit flow of the Danube from Serbia (S9 and S10). OS represents the result of very complex relations between oxygen consumption and its recovery processes in the water. Dissolved oxygen is consumed both in the processes of biochemical degradation of organic matter and the oxidation of nitrogen compounds, while the degree of oxygen saturation is directly related to the temperature regime, as well as to the intensity of the process of photosynthesis in the water. At all of the observed locations OS is present with high percentage share, which may lead to certain balancing of river's pollution caused by other parameters.

The results of the analysis show that there is a significant excess in values of PO_4-P and $E.coli$ at almost every location on the course of the river, which suggests that the protective measures should be taken at these sites to reduce or completely remove the sources of pollution. Also, there is an evident excess in values of total N, starting from the input, and NH_4-N towards the output profile of the river flow, ranking the Danube water quality on these locations into lower A2 category of EU Directive. The identified A2 and A3 water quality categories refer to the use of different water treatment methods (such as pre-chlorination, chlorination to break point, coagulation, flocculation, decantation, filtration, adsorption or final chlorination) to purify the water up to the quality of drinking water. However, better water quality tends to be achieved towards the exit profile as opposed to the entry profile of the Danube in Serbia, pointing at an important self-purification role of the Iron Gate gorge, located at the exit part of the river from the country.

Application of MCDM analysis in order to determine the level of environmental impact produced excellent results:

- Based on the weights from the official Serbian WQI calculation algorithm, the model for multi-criteria decision making was formed.
- By applying PROMETHEE method locations of potential environmental risk were determined and ranked according to the quality of water.
- Using GAIA plane, the most dominant variables that affect the quality of water at certain locations were identified as polluting parameters (SM, BOD-5, total N, NH_4-N and PO_4-P).
- Concentrations of identified pollutants were compared with limits of both EU and national recommendations, whilst deviations from the required values were determined.

5 Conclusion

The surface water quality of the Danube was assessed using WQI method at first. Then, the shortcomings resulting from solely applying the index method have been successfully repaired in combination with multi-criteria method, providing a broader picture of the actual quality of the observed water body.

Application of multi-criteria methods in water quality assessment exposes more information than traditional methods based on indices such as WQI, used for informing the public on the state of water quality. Presented results demonstrate that the use of PROMETHEE method along with its geometrical interactive option provide additional information about the interdependence between the quality parameters, between locations, as well as correlation between locations and parameters together. Creating an appropriate scenario for the evaluation of the water quality in MCDA also would not be possible without the use of an algorithm for calculating the water quality index that reveals the weight shares of each parameter in the overall water quality. So, combining the two methods, it is possible to conduct much thorough analysis of the surface water quality than by using each method alone.

Approach presented in this work is applicable to any surface water quality evaluation, not just for the river water quality. Proposed combined evaluation model is of great importance for the engineers and decision makers involved in water quality management. It simplifies the process of decision-making in the choice of a selection of certain locations with critical water quality, where appropriate measures for remediation of pollution should be taken. It could also help in creating more detailed reports and elaborations on the quality of water bodies.

From the point of creating a stable and healthy environment, this work highlights the significance of thorough protection of the Danube River. Construction of contemporary collectors and water purifiers at industrial sites along the river in Serbia could considerably improve the water quality of the river. Also, crucial requirement for Serbia is to supervise and protect its part of the Danube, while cooperating with other Danube riparian countries to implement equal protection measures on their parts of the Danube.

Briefly, the significance of this work is reflected in two major outcomes:

- Firstly, WQI and MCDM methods were combined to obtain an in-depth analysis of the surface water quality that could serve to engineers and decision makers involved in water quality management;

- Secondly, this combined approach was applied to analyze water quality of the most valuable water resource in Europe - the Danube, in order to contribute to the European efforts in preserving Danube water quality at the required level of quality.

The results of this research can be used for remediation of the identified pollutants of the Danube in Serbia. It can very well serve to all potential stakeholders, institutions and policy-makers interested in proper management of the Danube River in Serbia and across the entire Danube region. Even so, the results of the applied approach could serve as a basis for future research on water quality and water quality trends over the years, or even further, as a starting point for predicting water quality.

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