COMPUTING THE CCME WATER QUALITY INDEX FOR LAKE LUDAS

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Summary: *A water quality index (WQI) is a way to represent complex water quality data and communicate it to the general public. This paper represents an overview of the CCME WQI method. The considered method incorporates three main elements, the number of variables not meeting water quality objectives (scope), the number of times these objectives are not met (frequency), and the amount by which the objectives are not met (amplitude). As a result, a number between 0, being the worst water quality, and 100 being the best water quality, is attained that is used to describe the surface water's state. After an in depth analysis, the method is applied for the determination of the CCME WQI of Lake Ludas for the year 2012.*

Keywords: *water quality representation, CCME WQI, Lake Ludas*

1. INTRODUCTION

The water quality index is a way to describe and communicate the state a certain water body is in to the general public. The advantage of this approach is that it includes different water quality parameters that are representative for a certain location and time interval, and combines them into one number and a matching description. Consequently, instead of using complicated scientific data to represent the state of a considered water body, one can use an easily understandable description.

There are various methods to evaluate water quality index (WQI) of a surface water that can provide an insight into the spatial and temporal variation of the water. A short overview of the basic method is presented by Bhateria and Jain in [1]. In order to present the quality of a surface water both qualitatively and quantitatively, the Composite Water Quality Identification Index method (CWQII) was developed [2]. Various authors have compared different methods in order to determine the difference in the attained results [3,4,5]. One of the widely used methods for the representation of the WQI is the Canadian Council of Ministers of the Environment Water Quality Index method, CCME WQI, [6,7,8]. The presented research contains an overview of the CCME method. After the extensive description of the method, the authors gave a short consideration on the

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measurements included in the forthcoming study. Namely, any numerical evaluation of water resources relies on the previously conducted measurements [9]. The selected method is utilized for the evaluation of the WQI for Lake Ludas using measurements from 2012.

2. THE CCME WATER QUALITY INDEX METHOD

Details concerning the CCME waster quality index method can be found in the Canadian Water Quality Guidelines [10,11]. In this paper the authors gave an overview of this method in order to explain the general idea behind it and it's application on an actual case study.

The CCME WQI is computed according to Eq. 1.

$$\text{CCME WQI} = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right] \tag{1}$$

In Eq. factors F_1, F_2 and F3 present the scope, frequency and amplitude and are combined to calculate the CCME WQI, while factor 1.732 is introduced to scale the CCME WQI index from 0 to 100. The scope, F_1, shows the extent of the water quality data that are non-compliant over the time interval included in the analysis. More precisely, this is the number of water quality parameters that did not meet their objectives. The scope is computed according to Eq. 2.

$$\mathrm{F}_1 = 100 \cdot \left[\frac{\text{Number of parameters not meeting the objectives}}{\text{Total number of considered parameters}} \right] \tag{2}$$

The frequency, F_2, inserts into the computation the percentage of the individual tests that do not meet the objectives. The computation of the frequency is given with Eq. 3.

$$\mathrm{F}_2 = 100 \cdot \left[\frac{\text{Number of failed tests}}{\text{Total number of tests}} \right] \tag{3}$$

The third element of the method is the amplitude, F_3, that holds within itself the amount by which the objectives are not met. The computation of the amplitude is divided into the following steps:

- computing the excursion that shows the number of times by which an individual measurements fails the objective, evaluated using Eqs. 6. or 5.

$$\text{excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}} \right) - 1 \tag{4}$$

$$\text{excursion}_i = \left(\frac{\text{Objective}}{\text{Failed test value}_i} \right) - 1 \tag{5}$$

- determining the collective amount by which these individual tests don't comply with the objectives, called the normalized sum of excursions, nse, that is computed using Eq. 6

$$\text{nse} = \left(\frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{number of tests}} \right) \tag{6}$$

- computing the amplitude itself, Eq. 7., using the previously computed excursion and it's normalized sum,
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$$F_3 = \left(\frac{\text{nse}}{0.01 \cdot \text{nse} + 0.01} \right). \tag{7}$$

After determining the elements of the method, one can utilize Eq. 1 to determine CCME WQI. The attained number is between 0 and 100 where the lowest value 0 implies a very poor water quality, whereas the value 100 indicates excellent water quality. Finally, the established value of the CCME WQI is ranked into one of the five categories presented in Tab. 1.

Table 1. Water quality categories of the CCME WQI method

Value of CCME WQI	Water quality category
95-100	Excellent
80-94	Good
60-79	Fair
45-59	Marginal
0-44	Poor

3. APPLICATION OF THE CCME WATER QUALITY INDEX METHOD

The application of the CCME WQI computation is presented on the example of Lake Ludas. Lake Ludas is a shallow lake located near the town of Subotica in Serbia. It is a special natural preserve and is listed as a swamp area of international significance by the Ramsar Convention according to which it takes up the area of approximately 593 ha. Lake Ludas has two main inflows, one is from the Kires channel flowing from the Hungarian side, and the other is the Palic-Ludas channel. Due to it's significance, the quality parameters of the lake are fairly regularly monitored by the Public Health Institute Subotica who publish their measurements online. Using these measurements it is possible to conduct a water quality evaluation of Lake Ludas.

In this case, the authors chose to employ the WQI analysis using the data from year 2012. Before computing the CCME WQI it is necessary to select which of the water quality parameters are to be included in the quality evaluation. The selection of the representative parameters is done using Pearson's correlation. By computing the Pearson's correlation coefficient for all of the available water quality parameters, one can attain an insight into the influence these parameters have on each other and the water quality itself. The correlation coefficient can take the value between -1, suggesting no correlation, to +1, suggesting complete correlation of the considered parameters.

Table 2.Pearson's correlation coefficients, part 1

		T	pH	C	DO	COD	BOD$_5$	Chl-a
		˚C	-	µS/cm	mg/l	mg/l	mg/l	mg/m^3
T	˚C	1						
pH	-	0.620	1					
C	µS/cm	0.220	0.142	1				
DO	mg/l	-0.173	0.161	-0.782	1			
COD	mg/l	0.580	0.610	0.703	-0.453	1		
BOD$_5$	mg/l	0.364	0.352	0.557	-0.256	0.798	1	
Chl-a	mg/m^3	0.272	0.600	-0.100	0.306	0.441	0.314	1
SS	mg/l	0.455	0.724	0.120	0.107	0.481	0.358	0.692
TP	mg/l	0.298	0.573	0.164	0.084	0.453	0.369	0.199
PO$_4$	mg/l	-0.192	0.207	0.291	-0.121	0.120	0.014	-0.070
TN	mg/l	0.120	0.510	0.412	-0.037	0.676	0.571	0.517
TK	mg/l	0.283	0.619	0.341	-0.080	0.638	0.418	0.579
NO$_2$	mg/l	-0.546	-0.226	-0.228	0.365	-0.319	-0.115	-0.103
NO$_3$	mg/l	-0.409	-0.149	-0.126	0.323	-0.362	-0.200	-0.233
NH$_4$	mg/l	-0.429	-0.078	0.100	0.068	-0.064	0.086	-0.200

Table 3.Pearson's correlation coefficients, part 1

		SS	TP	PO$_4$	TN	TNK	NO$_2$	NO$_3$	NH$_4$
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
SS	mg/l	1							
TP	mg/l	0.515	1						
PO$_4$	mg/l	0.080	0.093	1					
TN	mg/l	0.614	0.477	0.229	1				
TK	mg/l	0.625	0.288	0.216	0.800	1			
NO$_2$	mg/l	-0.333	-.0326	0.409	0.131	0.157	1		
NO$_3$	mg/l	-0.261	-0.323	0.604	-0.058	-0.057	0.735	1	
NH$_4$	mg/l	-0.226	-0.108	0.506	0.119	0.224	0.701	0.580	1

The numerical values of the computed correlation coefficients are given in Tabs. 2 and 3, where the white columns with lighter letters mark the water quality parameters that were omitted from the CCME WQI computations (temperature, T, dissolved oxygen, DO, 5 day biochemical oxygen demand, BOD$_5$, orthophospathe, PO$_4$, and total Kjeldahl nitrogen, TNK). It should be pointed out that even though the temperature had high correlation to other parameters, it was decided not to include it into the following analysis due to the issues of selecting the objective for it throughout the year.

Finally, the following 10 parameters were included in the computation of the CCME WQI: pH, conductivity (C), bichromate chemical oxygen demand (COD), chlorophyll-a (Chl-a), suspended sediments (SS), total phosphorus (TP), total nitrogen (TN), nitrite nitrogen (NO_2), nitrate nitrogen (NO_3) and ammonium nitrogen (NH_4), as seen in Tabs. 2 and 3. Since there are available measurements of the water quality parameters at the north and south part of Lake Ludas, both of these data sets were included into the considerations. As a result, the total number of considered parameters was 10, while the total number of tests is computed as 10 parameters times 12 months times 2 data sets, giving a total of 240 tests. The objectives for the computation of the water quality index were taken from the Serbian National regulations and are given in Table 4.

Table 4. Objectives for the water quality parameters used to compute the CCME WQI

Parameter	SS	TP	Chl-a	C	COD
Unit	mg/l	mg/l	mg/m^3	µS/cm	mg/l
Objective	35	1	100	1500	50
Parameter	pH	TN	NO_2	NO_3	NH_4
Unit	-	mg/l	mg/l	mg/l	mg/l
Objective	8.5	10* or 20**	0.2	6	0.8

**-objective from May 1st until November 15th ,*

***-objective from November 16th until April 30th*

Tables 5 and 6 contain the measurements that were engaged into the CCME WQI computations, where the computed values of excursions are marked with grey color in column exc, while the first columns denote the lake part where the measurements were conducted (N for north and S for south), and the second columns, marked M. present the month at which the data were determined. The last row in both Tabs. shows the objective, marked Obj., and the partial sum of excursions for the given water quality parameter, denoted Σexc.

It should also be pointed out that the exc boxes that are left empty are those where the measurements meet the objectives.

The steps to computing the CCME WQI were given in Sec. 2. where the CCME WQI itself is computed according to Eq. 1. Before we can determine the CCME WQI, it is necessary to determine it's elements, the scope, Eq. 2, frequency, Eq. 3. and amplitude given with Eq. 7. Using Eq. 2. the scope is determined as follows:

$$F_1 = 100 \cdot \left[\frac{\text{No. of param. not meeting the objectives}}{\text{Total number of considered parameters}} \right] = 100 \cdot \left[\frac{7}{10} \right] = 70$$

The number of parameters not meeting the objectives can be seen from the last row of Tabs. 5 and 6. Columns Σexc that have values greater than 0 are the ones where the parameter didn't meet the objective at a certain point during the measurements. The exact time of when the parameter failed the objective can be seen from the exc boxes. If the box has a value that is greater than zero, than at that point the considered parameter failed the objective. Empty boxes indicate exc values that are less than zero and hence met the objectives, consequently they are not included into the computation of Σexc.

Table 5.Measurements and partial results, part 1

	M.	SS	exc	TP	exc	Chl-a	exc	C	exc	COD	exc
N	1	58	0.66	0.48		250	1.5	1093		112	1.24
	2	54.3	0.55	0.23		35.1		1363		98	0.96
	3	60	0.71	0.41		375	2.75	958		77	0.54
	4	185	4.29	0.57		421	3.21	1021		130	1.6
	5	96	1.74	0.51		125	0.25	1011		138	1.76
	6	115	2.29	0.58		562	4.62	991		168	2.36
	7	150	3.29	0.64		430	3.3	1187		244	3.88
	8	350	9	0.2		1406	13.06	1350		257	4.14
	9	230	5.57	0.94		1172	10.72	1501	0.001	330	5.6
	10	175	4	0.734		781	6.81	1459		296	4.92
	11	33.3		0.12		536	4.36	1180		210	3.2
	12	36.6	0.04	0.1		625	5.25	1089		120	1.4
S	1	48.8	0.39	0.62		97		1451		162	2.24
	2	76	1.17	0.23		46.80		1696	0.13	149	1.98
	3	47.5	0.36	0.3		94		1179		93	0.86
	4	67	0.91	0.07		70		1438		132	1.64
	5	33		0.25		125	0.25	1469		144	1.88
	6	22.5		0.29		234	1.34	1533	0.02	152	2.04
	7	56	0.6	0.46		256	1.56	1825	0.22	336	5.72
	8	38	0.09	0.11		62		2230	0.49	245	3.9
	9	170	3.857	0.82		375	2.75	2910	0.94	404	7.08
	10	200	4.71	0.7		312	2.12	2350	0.57	278	4.56
	11	55	0.57	0.130		566	4.66	1748	0.16	280	4.6
	12	33.3		0.127		703	6.03	1681	0.12	200	3
		Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc
		35	44.81	1	0	100	74.54	1500	2.65	50	71.1

The frequency of failed tests is:

$$F_2 = 100\cdot\left[\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right] = 100\cdot\left[\frac{124}{240}\right] = 51.67$$

The number of failed tests is determined by the number of measured data that failed the objectives.

Table 6.Measurements and partial results, part 2

	M.	pH	exc	TN	exc.	NO2	exc	NO3	exc.	NH4	exc.
N	1	8.68	0.02	19.94		0.113		0.53		3.03	2.78
	2	9.01	0.06	14.01		0.11		1.56		3.46	3.33
	3	9.19	0.08	9.93		0.046		0.82		1.95	1.44
	4	9.31	0.10	15.94		0.002		0.21		1.31	0.64
	5	9.26	0.09	9.11		0.003		0.05		1.01	0.26
	6	9.87	0.16	10.36	0.04	0.002		0.17		0.96	0.2
	7	10.09	0.19	18.9	0.89	0.003		0.15		1.51	0.89
	8	10.06	0.18	20.80	1.08	0.006		0.27		0.78	
	9	10.11	0.19	23.69	1.37	0.007		0.16		1.46	0.82
	10	10.63	0.25	17.95	0.79	0.006		0.19		1.8	1.25
	11	9.06	0.07	13.68	0.37	0.069		0.51		2.83	2.54
	12	8.95	0.05	13.58		0.062		0.287		2.74	2.43
S	1	8.36		17.62		0.007		0.29		0.79	
	2	8.62	0.01	12.31		0.033		0.45		3.52	3.4
	3	8.24		9.49		0.007		0.22		1.2	0.49
	4	8.17		12.32		0.006		0.36		1.39	0.73
	5	8.14		8.39		0.008		0.07		0.94	0.18
	6	8.75	0.03	6.60		0.004		0.31		1.44	0.79
	7	9.32	0.10	13.88	0.39	0.001		0.29		2.22	1.77
	8	9.49	0.12	13.42	0.34	0.001		0.33		1.03	0.29
	9	9.50	0.12	23.56	1.36	0.009		0.06		2.41	2.01
	10	10.05	0.18	20.29	1.03	0.006		0.4		2.05	1.56
	11	9.08	0.07	21.54	1.15	0.082		0.54		1.59	0.99
	12	8.57	0.01	14.15		0.006		0.258		1.4	0.75
		Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc
		8.5	2.07	0.02	8.81	0.2	0	6	0	0.8	29.55

In order to compute the amplitude, one should firs determine the nse that is computed by summing all of the Σexc values, for all of the considered parameters, and over all of the measured data, that was in this case 10 parameters, with 12 months of measurements and two sets of data, which is then reduced by the number of results that met their objectives. The amount by which the objectives are not met is:

$$F_3 = \left(\frac{\text{nse}}{0.01 \cdot \text{nse} + 0.01} \right) = \left(\frac{0.973}{0.01 \cdot 0.973 + 0.01} \right) = 49.31$$

Finally, the CCME WQI can be determined:

$$\text{CCME WQI} = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right] =$$

$$= 100 - \left[\frac{\sqrt{70^2 + 51.67^2 + 49.31^2}}{1.732} \right] = 42.26$$

According to the descriptions given in Tab. 1., the water quality of Lake Ludas is considered poor if computed using the CCME WQI method.

As it was presented, using this approach, the water quality of a surface water can be described using one number and a description that are based on a large number of data. This approach is much more acceptable when dealing with the general public who are usually the stakeholders managing these sites.

4. CONCLUSION

This paper presents the process of determining the CCME WQI. The first section of the work shows the equations used to compute the water quality index, while the second part of it gives an example by evaluating the CCME WQI for Lake Ludas. For the representation of the method, the authors selected the data from year 2012. where there were two sets of data, one for the south part of the lake, and another one for the north part of the lake.

After determining the CCME WQI it was established that the quality of Lake Ludas puts it in the range of poor quality with the CCME WQI of 42.26.

The importance of evaluating the WQI in general is a consequence that complicated scientific data that are gathered and used to monitor the water quality of a certain site need to be represented in a more approachable manner in order to make them understandable for the general public. This is the consequence of the fact that the final decisions regarding the management of these sites are made by stakeholders that are part of the general public. As a solution, instead of providing them with a large amount of various water quality parameter measurements, these data are included into the computation of a water quality index, that reduces these data into one number and an easily understandable word.

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REFERENCES

[1] Bhateria R. and Jain D. : Water quality assessment of lake water: a review. Sustainable Water Resource Management, 2016, vol. 2, , № 2, p.p. 161-173
[2] Xu Z.X. : Composite water quality identification index for environmental quality assessment of surface water. Journal of Tongji University (Natural science), **2005**, vol. 4, № 33, p.p. 482-488
[3] Ji X., Dahlgren R. A. and Zhang M. : Comparison of seven water quality assessment methods for the characterization and management of highly impaired river systems. Environmental Monitoring and Assessment, **2016**, vol. 188, № 15, https://doi.org/10.1007/s10661-015-5016-2
[4] Liu W. J., Li Z. B., Zou D. S., Ren C. J. and Pei Q. B. : The characteristics and evaluation of water pollution in Ganjiang Tail River. IOP Conference Series: Earth and Environmental Science 82, IOP Publishing, **2017**
[5] Lumb A., Sharma T. C., Bibeault J. F. and Klawunn P. : A Comparative Study of USA and Canadian Water Quality Index Models. Water Quality, Exposure and Health, **2011**, vol. 3, № 3-4, p.p. 203-216.
[6] Bilgin A. : Evaluation of surface water quality by using Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) method and discriminant analysis method: a case study Coruh River Basin. Environmental Monitoring and Assessment, **2018**, vol. 190, № 554, https://doi.org/10.1007/s10661-018-6927-5
[7] de Almeida G. S. \& de Oliveira I. B. : Application of the index WQI-CCME with data aggregation per monitoring campaign and per section of the river: case study - Joanes River, Brazil. Environmental Monitoring and Assessment, **2018**, vol. 190, № 195, https://doi.org/10.1007/s10661-018-6542-5
[8] Davies J-M. : Application and Tests of the Canadian Water Quality Index for Assessing Changes in Water Quality in Lakes and Rivers of Central North America. Lake and Reservoir Management, **2006**, vol. 22, № 4, p.p. 308-320
[9] Koch D. and Horvat Z. : Field measurements and hydraulic computation of a culvert. Journal of Faculty of Civil Engineering Subotica, **2018**, vol. 34, p.p. 57-66
[10] CCME :. Canadian Water Quality Guidelines for the Protection of Aquatic Life, CCME Water Quality index 1.0, User's Manual. CCME, Winnipeg, Manitoba, Canada., **2011**
[11] CCME: Synthesis of Research and Application of the CCME Water Quality Index, CCME Project No. 520-2012. Malahat, British Columbia, **2012**

ПРОРАЧУН CCME ИНДЕКСА КВАЛИТЕТА ВОДА ЗА ЈЕЗЕРО ЛУДАШ

Резиме: *Индекс квалитета вода (WQI) је начин на који се сложени подаци о квалитету вода приказују једним бројем и комуницирају са широм јавношћу. Овај рад даје преглед методе CCME WQI за одређивање индекса квалитета вода. Разматрана метода квалитет површинске воде приказује преко три основна елемента, броја параметара који не задовољавају циљану вредност, броја који показује колико пута циљана вредност није задовољена, и броја који показује за колико су циљане вредности премашене. Као резултат се добија број између 0, што представља најлошији квалитет воде, и 100, који представља најбољи квалитет воде, који се користи за дефинисање квалитета разматраног језера. Приказана метода је након исцрпног описа примењена на прорачун индекса квалитета језера Лудаш за годину 2012.*

Кључне речи: *приказ квалитета вода, , CCME WQI, језеро Лудаш*