INVESTIGATING THE EXTENT OF SPATIAL DIFFERENCES IN WATER QUALITY

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Summary: *The surface water quality index is used to more clearly display the state of the considered water quality. There are many different methods used to attain this goal. Depending on the employed method there is a number of parameters that should be included in the analysis in order to provide reliable results. This also alows the user to represent the water quality with only one number using data from a couple of years. This paper investigates the influence of spatial differences of the water quality within the same surface water, relying on the CCME WQI methoid. The research is conducted using the available water quality data on Lake Ludas.*

Keywords: *water quality, CCME WQI, spatial changes in CCME WQI*

1. INTRODUCTION

In order to represent the surface water quality to the general public an decision makers, the researchers usually rely on the water quality index WQI. This is a consequence of the fact that the evaluation of the water quality depends on a large amount of data that needs to be gathered, examined and processed in order to come to any reliable conclusions regarding the considered surface water's state. Displaying all of these complex water quality parameters to the general public would be unreasonable. As a solution, these data are implemented into the WQI to represent the state of the considered water body with a single number and a descriptive word.

Throughout the years researchers developed different methods for the computation of the WQI that can include large number of measurements through space and time. Bhateria and Jain gave an overview of some of the available methods in [1]. A method that allows the qualitative and quantitative representation of the surface water's quality is the Composite Water Quality Identification Index method (CWQII) explained in [2]. The differences when employing various methods were investigated by a large number of researchers [3,4,5]. In their research, Lumb et. al. found that the Canadian Council of Ministers of the Environment Water Quality Index CCME WQI is the strictest among the

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considered methods [5]. The CCME WQI method was considered by various researchers and a fair description can be found in [5,6,7,8].
Some of the issues that occur when dealing with measurements are given in [9,10]. Namely, all of these investigations rely on the gathered measurements, which is why it is at most importance to properly evaluate the gathered data in order to exclude possible errors. Furthermore, these measurements need to be processed and carefully considered which of them is to be included into the further analysis, since the results, and consequently the conclusions will depend on them. Additional complications in the process of the data evaluation is the fact that usually these sites where the data are gathered, have a tendency to display different characteristics at different locations.
The presented paper investigates such an example. The considered location is Lake Ludas in Serbia, where three separate sets of measurements are utilized to evaluate the sptial changes of WQI in the lake. The selected approach is the CCME WQI method. Using this method the authors evaluated the extent of the spatial alterations in the water quality using the measurements from year 2012.

2. MATERIALS AND METHODS

For the conducted study we selected Lake Ludas in Serbia due to it's international importance. Namely, Lake Ludas was named a Ramsar site, meaning it is a wetland of international importance. Consequently, there are regular water quality parameter measurements conducted on this area since 2011. These measurements are carried out on a monthly basis in multiple points allowing us to investigate the temporal and spatial changes of the lake's quality.
For the current investigation the authors choose the data from year 2012 in order to keep the focus on the spatial variations of the water quality parameters. The water quality analysis is implemented using the CCME WQI method.
In order to make a proper decision concerning the quality parameters that should be included into the WQI computation, one should implement the Pearson's analysis firs. By computing the Pearson's correlation coefficient for the available water quality parameters, it is possible to establish more objectively which of the parameters are representative for the evaluation of the considered site's water quality index. After carefully analyzing the available water quality parameters, the following ten parameters were established as representative for further considerations: 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).
The next step is the computation of the CCME WQI index. A detailed description of the CCME WQI method is found in [7,8]. This approach allows the researchers to prepare a more understandable representation of complicated scientific data for the general public. As a result, instead of showing a large number of measurements, often gathered over a couple of years, the quality of a certain site is described using a number and a word. The water quality index is determined using Eq. 1.

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

where factor F_1 marks the scope or the percentage of parameters not meeting the given objectives, F_2 is the frequency or the number of individual tests that did not meet the objectives, while F3 present the amplitude and includes the amount by which the objectives are not met. The number 1.732 in Eq. 1. is used to scale the computed water quality index index from 0 to 100, where low values of the CCME WQI indicate poor water quality, and higher suggest a better water quality. The categories of water quality for this method are displayed in Tab. 1. where we can see that there are five of them, ranging from excellent to poor. As is shown, using this method, the final result is a number and a matching word (excellent, good, fair, marginal or poor) describing the water quality of the investigated water body.

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

The evaluation of these factors are given by Eqs. 2, 3, 4 and 5.

$$F_1 = 100 \cdot \left[\frac{\text{Number of parameters not meeting the objectives}}{\text{Total number of considered parameters}} \right] \tag{2}$$

$$F_2 = 100 \cdot \left[\frac{\text{Number of failed tests}}{\text{Total number of tests}} \right] \tag{3}$$

$$F_3 = \left(\frac{\text{nse}}{0.01 \cdot \text{nse} + 0.01} \right), \quad \text{nse} = \left(\frac{\sum_{i=1}^{n} \text{exc}_i}{\text{number of tests}} \right) \tag{4}$$

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

Another value that needs to be defined in order to conduct the CCME WQI analysis are the objectives. The objectives present the limiting values of the water quality parameters

and are usually defined for every country. In this research we used the objectives defined by the Serbian National Regulations. The values of the engaged objectives are presented in the last rows of Tabs. 2, 3, 4, 5, 6 and 7. with the measured values.
The described method can be utilized to compute the WQI of a site using measurements over a large time interval gathered at one or multiple locations. By selecting to use only data of a single location the attained results are also of a local character. This is especially the case in situations where there are significant spatial variations of the quality parameters. On the other hand, including measurements gathered at various locations of a certain water body, we will attain a more universal representation of the water quality, since these data from different locations will finally provide only one CCME WQI of the complete site.

3. COMPUTING THE CCME WQI

In order to evaluate the spatial deviation of the water quality, the CCME WQI of Lake Ludas was computed for three locations, the north part of the lake, for which partial results are displayed in Tabs. 2 and 3., the middle part of the lake where the partial results are given in Tabs. 4 and 5. and the south part of the lake, for which the partial results are given in Tabs. 6 and 7.

Table 2.Measurements and partial results of the north part of Lake Ludas, 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
		Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc
		35	32.14	1	0	100	55.83	1500	0.001	50	31.6

It should be pointed out that the columns containing excursions (exc) are left empty in cases where the parameters did meet their objectives. Also, the last row of these columns contain the partial summation of the excursions (Σexc), that are later all summed up to give the nse value, Eq. 4. The columns of the water quality parameters in Tabs. 4 and 5 containing empty cells indicate that for some reason at that location, and that time, the considered parameter wasn't determined. These missing values are also taken into consideration when computing the CCME WQI.

Table 3.Measurements and partial results of the north part of Lake Ludas, 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
		Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc
		8.5	1.44	0.02	4.54	0.2	0	6	0	0.8	16.57

Table 4.Measurements and partial results of the middle part of Lake Ludas, part 1

	M.	SS	exc	TP	exc	Chl-a	exc	C	exc	COD	exc
M	1										
	2										
	3	120	2.43	0.28		156	0.56	1236		104	1.08
	4	103	1.94	0.38		247	1.47	1259		156	2.12
	5	92	1.63	0.37		156	0.56	1280		155	2.1
	6	24		0.29		265	1.65	1275		150	2
	7	90	1.57	0.35		390	2.9	1458		224	3.48
	8	53.3	0.52	0.12		273	1.73	1659	0.11	247	3.94
	9	154	3.40	0.48		687	5.87	1953	0.30	330	5.6
	10	70	1.00	0.141		976	8.76	1898	0.27	330	5.6
	11	40	0.14	0.14		762	6.62	1660	0.11	310	5.2
	12										
		Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc
		35	12.64	1	0	100	30.12	1500	0.78	50	31.12

Table 5.Measurements and partial results of the middle part of Lake Ludas, part 2

	M.	pH	exc	TN	exc.	NO2	exc	NO3	exc.	NH4	exc.
M	1										
	2										
	3	8.92	0.05	9.22		0.031		0.25		1.901	1.38
	4	9.08	0.07	12.88		0.003		0.3		1.636	1.05
	5	9.03	0.06	10.64	0.06	0.002		0.07		1.133	0.42
	6	9.5	0.12	7.17		0.002		0.38		1.158	0.45
	7	10	0.18	13.4	0.34	0.001		0.19		1.724	1.16
	8	9.81	0.15	14.49	0.45	0.002		0.27		1.46	0.83
	9	9.86	0.16	22.34	1.23	0.004		0.08		2.01	1.51
	10	10.4	0.22	22.43	1.24	0.005		0.27		2.039	1.55
	11	9.3	0.09	19.94	0.99	0.01		0.34		1.35	0.69
	12										
		Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc	Obj.	Σexc
		8.5	1.11	0.02	4.32	0.2	0	6	0	0.8	9.01

Table 6.Measurements and partial results of the south part of Lake Ludas, part 1

	M.	SS	exc	TP	exc	Chl-a	exc	C	exc	COD	exc
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	12.67	1	0	100	18.71	1500	2.65	50	39.5

Table 7.Measurements and partial results of the south part of Lake Ludas, part 2

	M.	pH	exc	TN	exc.	NO2	exc	NO3	exc.	NH4	exc.
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	0.63	0.02	4.27	0.2	0	6	0	0.8	12.98

The computed values of the CCME WQI are given in Tab. 8. while the graphical representation of the changes in the CCME WQI through space, including the value where the data for the two locations were combined are presented on Fig. 1.
By evaluating the computed values of the CCME WQI it can be seen that there are some alterations of the lake's quality throughout the space. This can also be observed by comparing the measured values of the water quality parameters. According to the values given in Tab. 8 the middle of the lake has the worst quality, while in 2012 the best water quality is detected on the south part of the lake. Furthermore, it is demonstrated that the water quality attained by evaluating all of the data together result in the CCME WQI values that are in between the values of separately evaluated water quality indices.

Table 8.CCME WQI of Lake Ludas

Part of Lake Ludas	CCME WQI	
North	40.81	Poor
Middle	39.51	Poor
South	44.16	Poor
Combined	41.54	Poor

The same results are displayed on Fig. 1, where we can visually observe the changes of the water quality throughout Lake Ludas. As it can be seen, the water quality decreases from the north side of the lake towards the middle, and then increases towards the south. The last column on Fig. 1 represents the CCME WQI determined using the combined values of the water quality parameters, and shows that the the water quality computed using the combined data results in the CCME WQI value in between the individually determined indices.

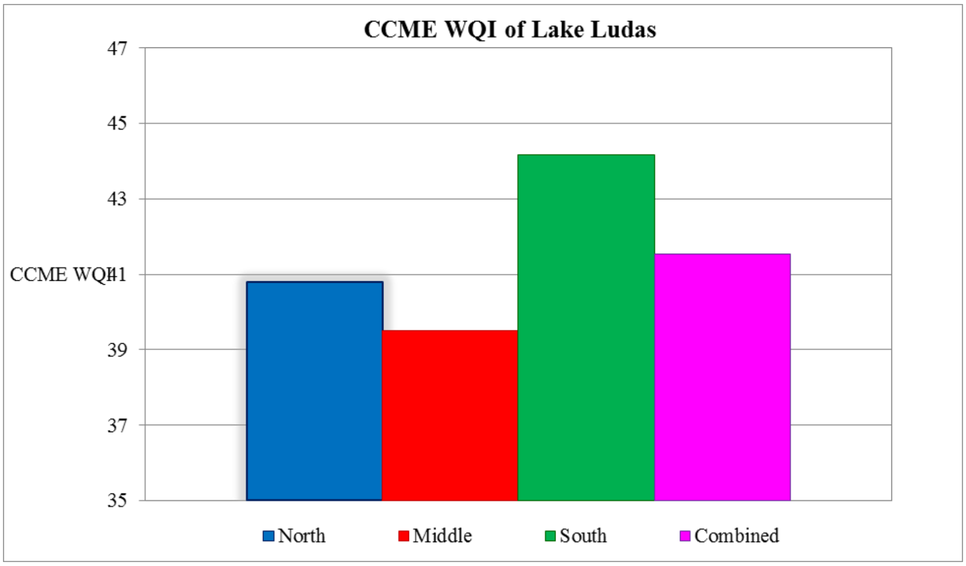

Figure 1. Graphical representation of the computed CCME WQI for Lake Ludas

4. CONCLUSION

In order to evaluate the spatial changes of the water quality of Lake Ludas the CCME WQI method was utilized. The existing water quality parameter measurements for 2012 are available at various locations which was essential in order to research the changes throughout the lake. The authors selected three sets of data, those gathered on the north section of the lake, in the middle part and on the south part of it. Before computing the CCME WQI, the Pearson's correlation analysis was conducted to determine which of the measured parameters are to be included in further computations. After selecting the representative parameters for the given location an time, the CCME WQI were computed for four cases, separately for three parts of the lake, and the value by using all off the available data.

Examining the results show that there are some spatial alterations of the water quality. The poorest quality was found in the middle of the lake, while the best quality was identified on the south part. Sadly, all of the results fall in the range of poor water quality index, suggesting necessary changes in the management approach.

Afterwards, all of these data were engaged to compute the joint CCME WQI. As expected the results were between the separately computed values, confirming that using spatially distributed data to evaluate a certain location will give a more general insight into it's water's quality.

For future references, the most reasonable approach would be implementing separate as well as combined WQI computations since that way we can get a more comprehensive insight into the investigated sites water quality state.

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ОДРЕЂИВАЊЕ МЕРОДАВНИХ ПАРАМЕТАРА ЗА ПРОРАЧУН CCME WQI

Резиме: *Индекс квалитета површинских вода се користи ради јаснијег приказа стања разматране површинске воде. За ово на располагању стоји велики број различитих метода. У зависности од одабране методе се дају предлози о броју параметара које је препоручљиво укључити у анализу како би се добили поуздани резултати. На овај начин се једним бројем може приказати квалитет воде и за вишегодишњи период.Овај рад анализира утицај просторних разлика квалитета воде унутар једног језера ослањајући се при томе на CCME WQI методу. Истраживање је спроведено користећи податке о квалитету вода језера Лудаш.*

Кључне речи: *квалитет вода, CCME WQI, просторне разлике у CCME WQI*