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Original article

Does Lake Balaton affected by pollution? Assessment through surface water quality monitoring by using different assessment methods

Roquia Rizk [a,b], Mesfin Alameraw [a], Mohamed Ali Rawash [c], Tatjána Juzsakova [a], Endre Domokos [a], Amor Hedfi [d], Mohammed Almalki [d], Fehmi Boufahja [e,*], Plavan Gabriel [f], Hesham M. Shafik [g], Ákos Rédey [a]

[a] *Research Centre for Biochemical, Environmental and Chemical Engineering, Sustainability Solutions Research Lab, University of Pannonia, Egyetem str. 10, H-8200 Veszprém, Hungary*
[b] *Biochemisrty Department, Faculty of Agriculture, Cairo University, Egypt*
[c] *Department of Animal Science, Georgikon Faculty, University of Szent István, Keszthely, Hungary*
[d] *Department of Biology, College of Sciences, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia*
[e] *University of Carthage, Faculty of Sciences of Bizerte, LR01ES14 Laboratory of Environment Biomonitoring, Coastal Ecology and Ecotoxicology Unit, 7021 Zarzouna, Tunisia*
[f] *Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
[g] *Department of Botany, Faculty of Science, Port Said University, Port Said 41522, Egypt*

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ABSTRACT

In order to maintain a good environmental status of surface waters, an assessment of water quality carried out at specific intervals to monitor the changes of water quality in function of time. Human knowledge and experience are currently focused on using assessment methods, especially the integration of multiple constraining factors and considering them in conjugation with the correct decision-making process concerning the environment. When surface water is highly exposed to human activities, either from recreational or economic activity, the degree of vulnerability is high, and the quality of surface water is highly compromised. In case of Lake Balaton, there are many activities that can disrupt water dynamics. The first goal of this study is to determine the location of the least and most polluted sites around Lake Balaton. The processing of data was carried out by using multi-criteria decision techniques and environmental impact assessment method based on physical–chemical parameters in comparison with the limiting parameters. Based on the results of those methods water quality needs to be improved in western parts of the lake by using several geoengineering treatment techniques. This work covers a novel approach to comparing methods based on sum of ranking differences, whereas many method comparison studies suffer from ambiguity or from comparisons not being quite fair. This problem can be avoided if there are differences between ideal and actual rankings.

1. Introduction

Lake Balaton (northern latitude 46° 71′ and 47° 01′ and the eastern longitudes 17° 24′ and 18° 16′, 104.84 m altitude) is the largest shallow lake in Central Europe. It is connected to Danube River via Sió channel and is situated in the western part of Hungary (Balogh et al., 2017), covers a surface of 596 km^2, a volume of 1.9 × 10^9 m^3, has an average depth of 3.25 m (Tátrai et al., 2000) and represents one of the main touristic attractions and recreational spa. (Polyák and Hlavay, 2005; (Tullner and Cserny, 2003). For the ease of national surface water management, the Hungarian government has divided four main watershed regions that are River Danube, River Drava, River Tisza, and Lake Balaton. TheHungarian National Water Framework Directive recognises 16 different types of water bodies; Lake Balaton belongs to the Typology 16 according to the Decree No. "10/2010 (VIII.18.) of VM" (MSZ, 2010). The methodology, which is deployed here in this study, uses the 2010 version of the Decree and all the threshold values are according to the 2010 standard. Environmental impact assessment (hereafter EIA) studies comprise the mechanisms that are employed to assess the relation between human activities and their impact on the environment, which aims the environmental protection, future improvements

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* Corresponding author.
E-mail address: fehmiboufahja@yahoo.fr (F. Boufahja).

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and sustainable development (Németh et al., 2017). EIA represents a package of the well-defined procedures, which requires a thorough discussion. Normally, it comprises the following major points: the project screening, scoping, consideration of alternatives, project actions, description of baseline conditions, impact identification, prediction of impacts, evaluation of significance, public consultation and negotiations with authorities (Utasi et al., 2014), as well as review actions, recommendations on mitigation measures, decision-making and monitoring (Glasson et al., 2013). The aquatic environmental index (hereafter AEI) can provide excellent and quick information on the quality status of any given surface water body through analysing and producing a quantity index (hereafter QI) of several water quality parameters as a single metric. Hence, AEI has a vital role in management and operations of measures to be taken, until the surface water quality of given water body reaches a good ecological status. Moreover, the quality of the aquatic environments has been incessantly deteriorating worlwide (Caglar et al., 2019) requiring a continuous need for operational analysis and assessment of the methodological development, covering also the economic feasibility and the technological advancements, in order to keep the ecological status sustainably in good conditions (Foden et al., 2008).

The AEI methodology was developed for calculating the environmental impact index by employing only physical–chemical parameters of surface waters. The AEI methodology is considered a quantitative EIA method, since the basic development procedures follow the weighting, standardization and congruence of water chemistry parameters (Németh et al. 2017).

Given the increasing pressure to quantitatively express the environmental impacts, the methods in use were considered to be beneficial because they can compare different project alternatives. The multi-criteria decision-making method and the Technique for Order Preference by Similarity Systems (TOPSIS) (Herva and Roca, 2013) can be further employed, as well as to support the decision-making process.

The application of various assessment techniques helps the interpretation of complex data matrices to better understand the water quality and the ecological status of the studied systems. This allows the identification of potential factors that influence the aqatic environment systems and represents a valuable tool for a further reliable management of water resources (Shrestha and Kazama, 2007). The benefits of combining different methods are the maximisation of the advantages of these methods and the avoidance of the inherent the differences between methods, by promoting the Sum of ranking differences (hereafter SRD), a novel statistical method that is rapidly becoming popular in various fields of applied science, such as analytical chemistry (Andrić, 2018). The SRD evaluation method was also used to explore the pharmacokinetic properties in pharmacology (Ristovski et al., 2018). By using the SRD in the multi-objective analysis, the process of decision-making by scientists becomes the optimum solution in various fields of engineering (Lourenço and Lebensztajn, 2018).

2. Material and methods

The current paper deals solely with water chemistry parameters to define water quality; however, this method allows the additional use of supplementary parameters such as the biological, hydro-morphological, other specific contaminants as well. The devised algorithm is flexible and can be further extended by including additional evaluation criteria, if needed.

2.1. Sampling strategy

This study was carried in Lake Balaton and water samples from 15 sites were taken along the lake, in September 2018 (Fig. 1). The

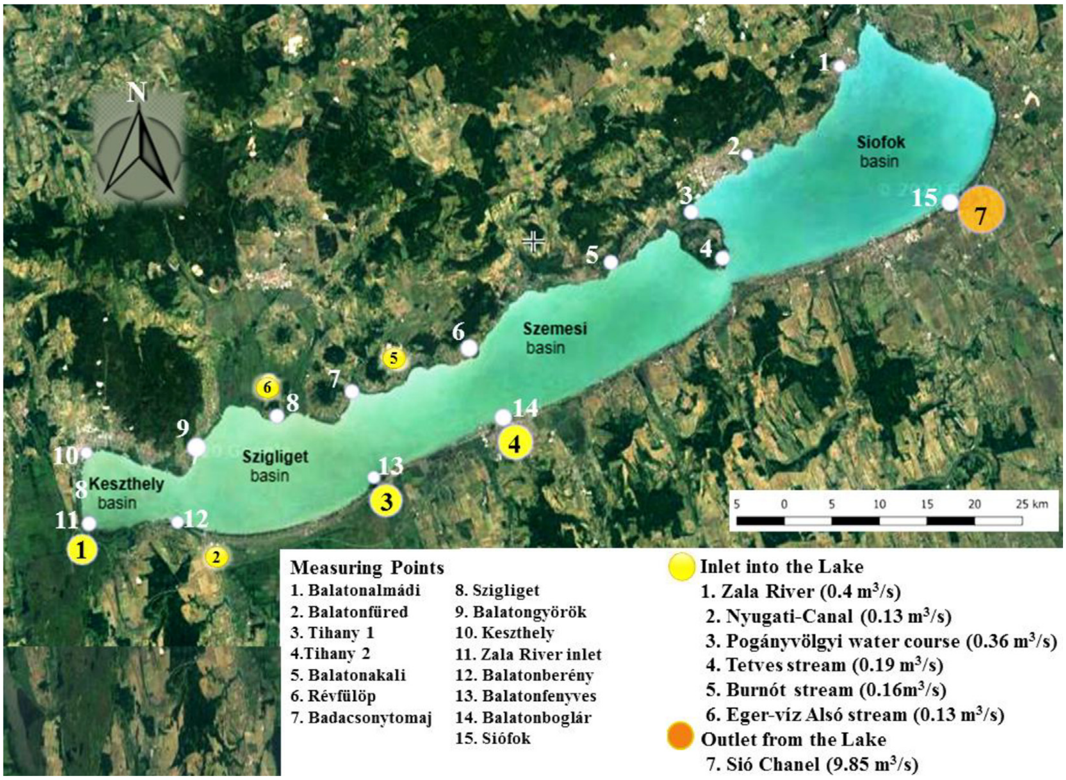

Fig. 1. Measuring points and main water supplies/inlets and discharge/outlet points of Lake Balaton.

Table 1
Surface water physical–chemical parameters quality class developed by Németh et al. (2017) in harmony with Hungarian National Standard.

Physical-chemical parameters							
	Quality classes qCi and categories						
	Quality class	1	2	3	4	5	Limit values
	Quality category Parameter	Bad	Weak	Proper	Good	Excellent	
1	Chla, μg/L	>22.5	22.5	15	12	<9	15
2	TU, NTU	>100.00	100	50	20	<10.00	50
3	pH $_{acidic}$	<5.00	5.50	6.00	6.50	7.00	7.80
4	pH $_{alkaline}$	>11.00	10.00	9.00	8.00	7.00	9.20
5	EC, μS/cm	>1200	1200	800	640	<480	800
6	DO, mg/L	<6.00	6	7.5	8.45	>9.38	7.5
7	OS, %	<64	64	80	90	>100	80
8	BOD_5, mg/L	>3.80	3.80	2.50	2.00	<1.50	<2.50
9	COD, mg/L	>45.00	45	30	24	<18.00	30
10	NH_4-N, mg/L	>0.075	0.075	0.05	0.04	<0.03	<0.05
11	NO_3-N, mg/L	>0.09	0.09	0.06	0.05	<0.04	<0.06
12	NO_2-N, mg/L	>0.05	0.05	0.03	0.02	<0.01	<0.02
13	TN, mg/L	>2.10	2.10	1.40	1.12	<0.84	<1.40
14	PO_4-P, mg/L	>0.015	0.015	0.01	0.008	<0.006	<0.01
15	TP, mg/L	>0.18	0.18	0.12	0.096	<0.072	<0.12
16	TOC, mg/L	>50	50	10	5.0	<2.0	10

sampling strategy was done according to the Hungarian Standard MSZ ISO 5667–4:1995 (MSZ 2010). The water samples were taken at a depth of half a meter and 70 m distance from shores, excepting those that did not had access from beach and required the use of an engine boat. The following six physical–chemistry parameters were measured on site, according to the official Hungarian measurement standards: temperature, turbidity (hereafter TU) (MSZ EN ISO 7027:2000), electric conductivity (EC) by Specific conductivity (NOETEK-PONSEL Digital sensor C4E: Conductivity/Salinity Datasheet) (MSZ 448–32:1977), pH (MSZ 1484–22:2009), oxygen saturation (OS) and dissolved oxygen content (DO) (MSZ EN ISO 7027:2000). Whereas, nutrient content determinations including total phosphorus (TP) (MSZ 448–18:2009), *ortho*-phosphate (PO_4-P) (MSZ 448–18:2009), total nitrogen (TN) (MSZ 12750–20:1972), ammonium nitrogen (NH_4-N) (MSZ ISO 7150–1:1992), nitrite-nitrogen (NO_2-N) (MSZ 1484–13:2009)) and nitrate-nitrogen (NO_3-N) (MSZ 260/11–71)), total organic carbon (TOC) (MSZ EN ISO 5667–3:1998), chemical oxygen demand (COD) (MSZ ISO 6060:1991), and biochemical oxygen demand (BOD_5) (MSZ EN 1899–2:2000) were carried out in laboratory of the Institute of Environmental Engineering, University of Pannonia Veszprem. TOC was measured by using Vario TOC Analyzer (TOC/TN Analyzer, Version 19.12.2012, Elementar Analysensysteme GmbH) based on EN1484 EU-Standard. Plastic airtight water bottles were used to collect the water samples.

Ponsel Odeon digital handheld instrument has been used for on-site measurements of TU, EC, pH, DO, and OS. The instrument has the ability to read and record in real time the data from the sensor. The sensors have the following technical specifications: pH sensor (pH range 1–14), turbidity sensor (Nephelometric turbidity (NTU) value with direct measurement units), EC sensor (range: 0–2000 μS/cm), OS sensor (detection range 0 – 200% SAT), DO content sensor (measuring range 0.00 – 20.00 mg/L) and Chl-a optical sensor: TRIOS UV-fluorescent measuring probe with a measurement range of 0–200 μg/L. The average temperature recorded due date was 29/12 °C max/min, respectively (AccuWeather, 2018).

2.2. Aquatic environmental index

The protocol of AEA method was devised by Németh et al. (2017). Five water quality classes and categories were used during the assessment of Aquatic Environment Index (AEI). The methodology uses the physical–chemical parameters of surface water to assess and quantify the quality of any surface water body, based on the standards of Hungary (MSZ, 2010), which is in harmony with the Water Framework Directive of European Union (WFD, 2000). The following steps were employed to carry the sampling methodology accordingly: first, the typology of the water body was established, followed by the selection of the cluster of water quality class based on threshold values specified by the Hungarian National Standard (MSZ, 2010) and then compared of a two-by-two strategy, followed by the aggregation of weighted indices obtained from the correlation of physical–chemical matrices and AEI (Németh et al., 2017). The surface water quality categories can be ranked into five different classes, according to Németh et al. (2017) from 1 to 5, simply based on the threshold values of physical–chemical water quality parameters, according to the Hungarian National Standard (Table 1). Class No. 1 indicates a "bad" water quality state with a high pollutant content, class No. 2 indicates a "weak" quality state, with a high pollutant content but slightly better than the previous class, class No. 3 refers to a "proper" state, which represents a moderate case, class No. 4 refers to a "good" water quality condition and finally, class No. 5 is considered as "excellent" and represents a very low level of pollutants' concentrations or pristine conditions. To prove the compliance of these quality classes, four different types of mathematical equations were been developed for various groups of physical–chemical parameters.

In the calculation of weight indices, numerical values were assigned to create a more precise relationship among physical–chemical parameters. According to Németh et al. (2017) methodology, five uneven numbers 1, 3, 5, 7, and 9, respectively, were assigned as a numerical representation of the above degree of comparison. Intermediate even numbers were also been noted as relevant representations, such as 2, 4 and so forth. After the development of the matrix and normalization (i.e., the values of the matrices divided by the aggregate of all parameter values of the weight indices) the average value was calculated for each parameter. To calculate the weight indices (WI), the mean result needs to be multiplied by 100, to standardise the result as percentages. The WI indicates the priority of various employed physical–chemical parameters; hence, the WI of phosphorous shows the highest impact as compared to other parameters, whereas the turbidity value was found as the least important. Such an output leads to the conclusion that the phosphorous content has the highest contribution to the assessment of pollution or the one that endangers most the surface water quality compared to other measured physical–chemical parameters. The weight index values were determined based on long-term monitoring data of the Hungarian water bodies. The weight indices were calculated using to an Analytical Hierarchy Process (AHP) pairwise comparison methodology, which uses the deviations from the good water status assessed according to the Water Framework Directive.

For validation, the summing of all weight indices must be equal to unit. The values of WI for the 15 employed parameters are given in Table 2. In theese calculations, the total phosphorus and orthophosphate contents comprise the maximum WI, with contributions of 16.62% and 15.75%, respectively. The water turbidity was considered as the least influential weighted indice, with 0.98% and 1.18% contribution, respectively. Once the total summation of the weight index was approved as equal to unit, the AEI is calculated according to the following equation:

$$AEI = \frac{\sum_{i=1}^{n} QC_i x WI_i}{n}$$

where AEI is the aquatic environment index, the QC_i represents a given quality class for the chemical parameter I, the WI_i is the weight indicex for the water chemical parameter i and n is the number of chemical parameters employed (e.g. the number of parameters used in this study is fifteen, n = 15).

The substitution method was employed to calculate the mean AEI values and AEI intervals and are given in Table 3. The minimum and the maximal threshold values of the intervals were also calculated by averaging the neighboring AEI figures. For example, (6.67 + 13.33) / 2 = 10. In this way, the top figure of the bad interval equals 10.

2.3. The employed technique for assessing the order preference by similarity to ideal solution methods

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was used previously and proved to be a reliable multiple criterion decision-making methods (MCDM). The TOPSIS procedure is based on an initiative and simple idea that maximizes the benefit, first developed by (Hwang and Yoon, 1981). In the TOPSIS technique the basic solution method is defining positive and negative ideal (non-ideal) solutions (Yoon and Kim, 2017). The positive ideal solution includes the best available value of employed parameters, whereas the non-ideal solutions represents the worst available value of a given parameter. Finally, the most parsimonious solution comprises both the shortest distance from the ideal solution and the longest from the non-ideal (Ishizaka and Nemery, 2013). The simplicity, rationality, comprehensibility, good computational efficiency and ability represent the advantages of this method (Mardani et al., 2014).

The ideal solutions are not probable, and each alternative solution has an intermediary ranking value between the ideal and the worst solution (Shyjith et al., 2008). Regardless of the absolute accuracy of rankings, the comparison of various different solutions under the same set of selection criteria allows an accurate weighting of the relative solution suitability and hence an optimal solution selection procedure. The TOPSIS method was applied to assess which sampling point is more or less polluted.

Table 2
The weight indices (WI) of water chemistry parameters.

No.	Physico-chemical water parameter	WI
1	Chla	1.23
2	TU	0.98
3	pH	2.59
4	EC	1.96
5	DO	7.81
6	OS	7.81
7	BOD_5	4.84
8	COD	9.79
9	NH_4-N	4.13
10	NO_3-N	4.13
11	NO_2-N	4.13
12	TN	10.50
13	PO_4-P	16.62
14	TP	16.62
15	TOC	6.84

Table 3
Evaluation categories of the quality class clusters in consideration with 15 measured parameters.

Quality Category	Mean value	AEI interval
Bad	6.67	10.00 > AEI
Weak	13.33	10.00 ≤ AEI < 16.67
Proper	20.00	16.67 ≤ AEI < 23.33
Good	26.67	23.33 ≤ AEI < 30.00
Excellent	33.33	30.00 ≤ AEI

2.4. Simple additive weighting method

The Simple Additive Weighting (SAW) method, also known as the weighted and simple weighted scoring method was also applied in this study. This method is commonly used for multiple decisions attribute (MADM) tools and the basic concept relies on calculating the weighted sum of performance ratings for each alternative on all attributes. The SAW method requires beforehand the normalizing of the decision matrix to a scale comparable to the other alternative rating methods in use (Valipour et al., 2018).

3. Results

The values of the physical–chemical parameters measured are given in Table 4. In site 11, the DO concentration (1.44 mg/L) with 16.30 OS (%), showed the lowest values and was considered inappropriate for the aquatic ecosystem, same as for the nutrients content, COD, Chla, turbidity and TOC, which recorded high values in the very same site.

3.1. Aquatic environmental index results

The AEI evaluation carried for the year 2018 for Lake Balaton showed quality ranges varying between “weak” to “good”. For seven sites the water quality felt in the “proper” quality class, whereas other seven measurement sites were classified as “good” water quality classes. The inlet point of the River Zala shows “weak” water quality. Accordingly, the site 15, Siófok showed the highest values, of 26.94, whereas the smallest AEI was calculated for site 11(11.57). The second weakest result was also recorded at site 8, Szigliget, with a value of 17.22 (Table 5), exhibiting the worst result for the whole lake. The mean of AEI was 23.31.

In what concerns the four basins of Lake Balaton, the measurements done in Szigliget and Keszthely basins showed lower AEI values compared to Siófok and Szemes. As Fig. 2 shows, all AEI values from the eastern part of the lake (sites 8–12) do not reach the good AEI category, emphasising the need for further works to improve water quality in this part of the lake.

The AEI result showed that water quality from the western part of the lake was deteriorated and contains relatively higher pollutants load compared to the eastern part. As confirmed too by the GIS map output presented in Fig. 3, sites 8, 9, 10, 11 and 12 showed a clear difference in comparison with the rest of sampling points, which included the Keszthely and Szigliget basins. With a weak

Table 4
Measured results of physical–chemical parameters and their limit values.

Site No	Chl-a (μg/L)	TU	pH	EC (μS/cm)	DO (mg/L)	OS (%)	BOD_5 (mg/L)	COD (mg/L)	NH_4-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TN (mg/L)	PO_4-P (mg/L)	TP (mg/L)	TOC (mg/L)
1	2.24	26.00	8.94^{-}	754^{-}	10.76^{+}	121^{+}	2	19.50	0.07	0.001	n.d.	1.82	0.02	0.07	18.03
2	2.12^{+}	24.30	8.76	743	8.86	104	n.d.	16.75	0.06	0.002	0.38	1.86	0.03	0.04	14.06
3	3.52	14.40	8.76	744	8.79	101	n.d.	14.50	0.01^{+}	0.001^{+}	n.d.	1.78	0.01	0.04	12.89
4	2.46	3.67	8.75	731	9.19	107	n.d.	12.25	0.02	0.001	n.d.	1.92	0.03	0.01^{+}	15.81
5	2.86	3.17	8.61	721	8.76	101	2	14.00	0.21	0.002	0.11	1.77^{+}	0.01^{+}	0.21	12.55
6	2.93	7.53	8.58	703	9.30	109	n.d.	24.75	0.033	0.002	n.d.	1.80	0.01	0.05	13.11
7	4.20	3.77^{+}	8.43	682	8.15	96	1	15.25	0.09	0.003	n.d.	1.92	0.01	0.09	13.75
8	4.45	16.30	8.61	678	8.03	97	4	21.50	0.06	0.002	0.64	1.94	0.01	0.28	14.89
9	4.80	14.60	8.69	653	9.46	113	n.d.	17.75	0.09	0.001	0.59	2.08	0.02	0.30^{-}	14.65
10	5.07	2.37	8.81	650	10.51	127	n.d.	20.00	0.22	0.002	n.d.	2.09	0.02	0.18	15.38
11	11.07^{-}	39.65^{-}	7.76^{+}	594^{+}	1.44^{-}	16^{-}	4	43.25^{-}	0.23^{-}	0.002	n.d.	2.43^{-}	0.12^{-}	0.20	22.33^{-}
12	6.62	23.70	8.24	640	6.98	81	n.d.	17.25	0.12	0.001	n.d.	1.99	0.01	0.06	14.27
13	6.16	31.90	8.73	670	8.31	99	n.d.	17.00	0.12	0.002	n.d.	2.05	0.01	0.01	16.62
14	6.01	6.23	8.71	673	10.29	120	n.d.	12.75	0.06	0.004^{-}	n.d.	1.98	0.01	0.03	13.14
15	6.81	7.59	8.50	737	9.73	115	n.d.	11.50^{+}	0.04	0.001	n.d.	1.88	0.01	0.05	12.02^{+}
Limit value	<15.00	50.00	8.30	<800	7.50	80.00	<2.50	<30.00	<0.05	<0.020	<0.06	1.40	<0.01	<0.12	<10.00

n.d. no data.
+ Indicates the relatively best quality.
– Represents the highly polluted site.

Table 5
Measurement sites and AEI value with quality classes.

Measurement site	Measurement Site Name	AEI	Quality Class
1	Balatonalmádi	22.10	proper
2	Balatonfüred	22.94	proper
3	Tihany 1	26.04	good
4	Tihany 2	25.00	good
5	Balatonakali	18.83	proper
6	Révfülöp	25.63	good
7	Badacsonytomaj	23.38	good
8	Szigliget	17.22	proper
9	Balatongyörök	18.30	proper
10	Keszthely	19.92	proper
11	Zala River inlet	11.57	weak
12	Balatonberény	23.31	proper
13	Balatonfenyves	25.47	good
14	Balatonboglár	25.28	good
15	Siófok	26.94	good

value ($10.00 \leq$ AEI < 16.67), site 11 represents a polluted area of Lake Balaton. The anthropogenic impacts are significant in this part of the lake and the remediation possibilities are limited. In conclusion, the mitigation techniques and future measures are requested, same as significant financial costs. Moreover, the average value of AEI for the whole lake is 22.13 and considerd as proper water quality class ($16.67 \leq$ AEI < 23.33). Overall, the water body is moderately polluted and the anthropogenic impacts are present within this lentic ecosystem.

3.2. Multi-criteria decision-making techniques results

Data on water quality parameters of various sites are given in Table 6. As the aim of the calculation was to detect polluted sites in Lake Balaton, so it should be considered that the closest value to 15 shows a higher water pollution level.

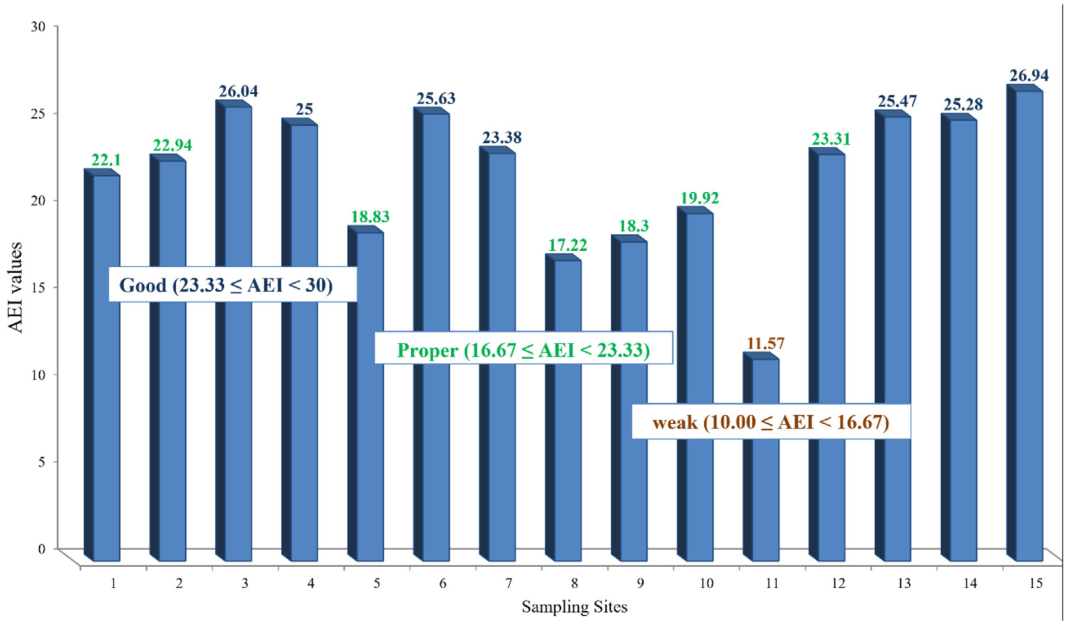

Fig. 2. Aquatic Environment Index values at fifteen measurement sites around Lake Balaton, blue-colored columns indicate the value of AEI.

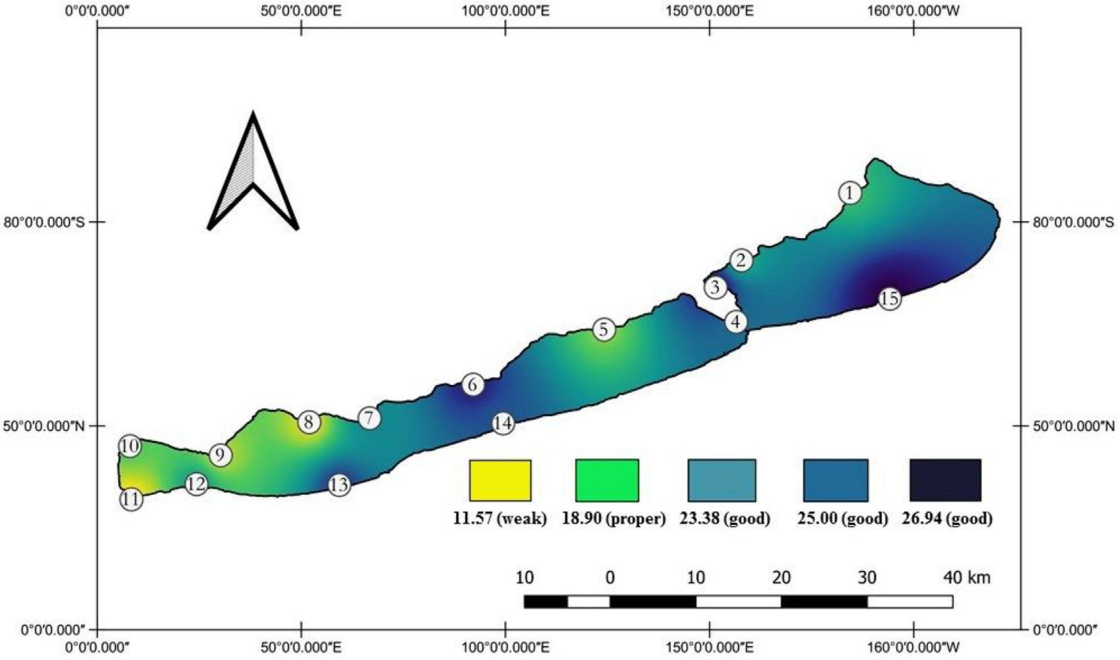

Fig. 3. Water quality status among the basins of Lake Balaton based on AEI values.

Table 6
The ranking of locality pollution by TOPSIS and SAW methods.

Site No.	Measurement Site Name	TOPSIS	SAW
1	Balatonalmádi	10	10
2	Balatonfüred	8	7
3	Tihany 1	2	2
4	Tihany 2	9	3
5	Balatonakali	11	11
6	Révfülöp	7	9
7	Badacsonytomaj	6	8
8	Szigliget	13	12
9	Balatongyörök	14	14
10	Keszthely	12	13
11	Zala River inlet	15	15
12	Balatonberény	4	4
13	Balatonfenyves	1	5
14	Balatonboglár	5	6
15	Siófok	3	1

Therefore, the identification of the polluted sites was defined by calculating the maximum and the minimum relative vicinity, which approximately situate near the ideal answer calculated for 15 sites, emphasizing that the rank No.1 showed the highest water quality for the lake, whereas the rank No. 15 showed the least water quality around the lake. Based on the TOPSIS ranking evaluation, site 11 exhibited the most polluted water, and site 13 was the least polluted site. However, according to the SAW ranking evaluation, the most polluted site was 11 and the least polluted site was 15.

Table 6 show that both ranking methods (i.e. TOPSIS and SAW) target the Zala River inlet as the most polluted site.

The TOPSIS evaluation showed that the dark blue shaded colour (Fig. 4) at site 13 (Balatonfenyves) indicate the highest water quality and the worst water condition are registered at site 11 (Zala River inlet site) which appears on the map by yellow shaded color. Regarding the distribution of sites around the lake and the division of basins, the results showed that Szemes and Siófok basins comprised a higher water quality than Keszthely and Szigliget.

The map represented in Fig. 5. showed that the SAW evaluation method ranked Lake Balaton into 15 classes. The dark blue shaded colour at site 15 (Siófok) and site 13 (Balatonfenyves) illustrates the best and the worst water conditions. As can be observed at site 11, the Zala River inlet site appeares on the map as yellow shaded colour. The results show that Szemes and Siófok basins represent the highe water quality than Keszthely and Szigliget basins.

3.3. Comparison of the results with sum of ranking differences

The sum of ranking differences represents a simple but effective statistical tool to rank and assess different solutions based on a reference point (Héberger, 2010). The absolute values of differences for the ideal and actual rankings were summed and the procedure was iterated for each (actual) method. The SRD values were obtained as such as to provide a way to order the methods as simple as possible. If the ideal ranking is not known, it can be replaced by the average vales (i.e. maximum or minimum of all methods or by a known sequence). The SRD corresponds to the principle of parsimony and provides an easy to implement tool to evaluate the methods: the best method has the smallest summation and the models and other items can be similarly ranked this way.

The purpose of using the SRD was to avoid the differences between two MCDM ranking evaluation methods and for using the AEI assessment method as a reference factor. Table 7 represents the ranking of the water quality along Lake Balaton by TOPSIS and SAW methods, as well as the average figures of the outcomes of these methods and of AEI values combined. The AEI values were arranged in ascending order; the maximum value (No. 1) had the highest preference. The Zala River inlet site showed the same rank for all evaluation methods (15). As Fig. 6 shows, the AEI values (green line) are in accordance with the TOPSIS evaluation method (blue line) and SAW evaluation methods (red line).

The average value of all three methods was used as gold reference. The underlying rationale was to avoid the differentiation of results following the combination of these methods. Fig. 7. shows the compatibility and difference between the ranking of methods,

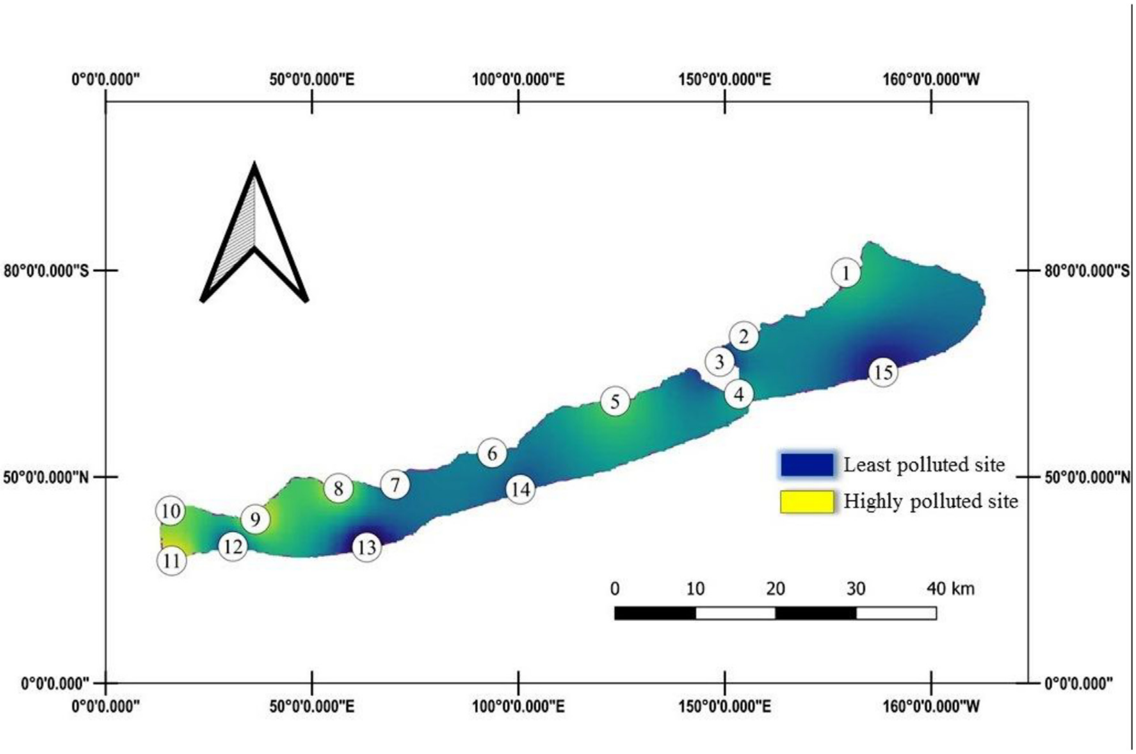

Fig. 4. The outcome of TOPSIS evaluation method along Lake Balaton.

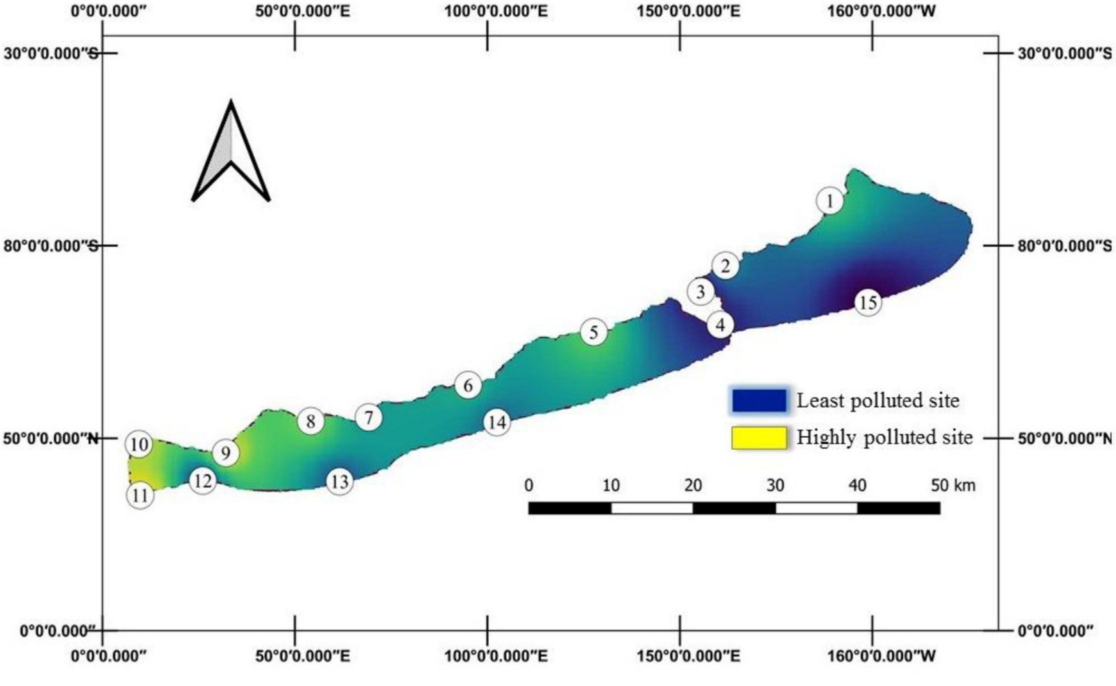

Fig. 5. The outcome of SAW evaluation method along Lake Balaton. Dark blue color illustrates the least polluted site, and light green illustrates highly polluted site.

such as for sites 1, 3 and 11, wich matched well in the ranking system of all three evaluation methods (i.e., TOPSIS, SAW and AEI).

Table 7 represents the SRD values, the smaller the sum, the better the method. This translates into the TOPSIS value of 10.7 being closer to AEI (12) rather than to the SAW method (14.7).

4. Discussion

The result of this workshowed that in the western part of the lake, the water quality was deteriorated and contains a relatively higher amount of pollutants compared to the eastern part. As

Table 7
The ranking of water quality by different evaluation methods.

Water final evaluation	TOPSIS Rank	SAW Rank	AEI Rank	Gold reference (average)	Diff. TOPSIS	Diff. SAW	Diff. AEI
Balatonalmádi	10	10	10	10.0	0.0	0.0	0.0
Balatonfüred	8	7	9	8.0	0.0	1.0	1.0
Tihany 1	2	2	2	2.0	0.0	0.0	0.0
Tihany 2	9	3	6	6.0	3.0	3.0	0.0
Balatonakali	11	11	12	11.3	0.3	0.3	0.7
Révfülöp	7	9	3	6.3	0.7	2.7	3.3
Badacsonytomaj	6	8	7	7.0	1.0	1.0	0.0
Szigliget	13	12	14	13.0	0.0	1.0	1.0
Balatongyörök	14	14	13	13.7	0.3	0.3	0.7
eszthely	12	13	11	12.0	0.0	1.0	1.0
Zala River inlet	15	15	15	15.0	0.0	0.0	0.0
Balatonberény	4	4	8	5.3	1.3	1.3	2.7
Balatonfenyves	1	5	4	3.3	2.3	1.7	0.7
Balatonboglár	5	6	5	5.3	0.3	0.7	0.3
Siófok	3	1	1	1.7	1.3	0.7	0.7
SRD					10.7	14.7	12.0

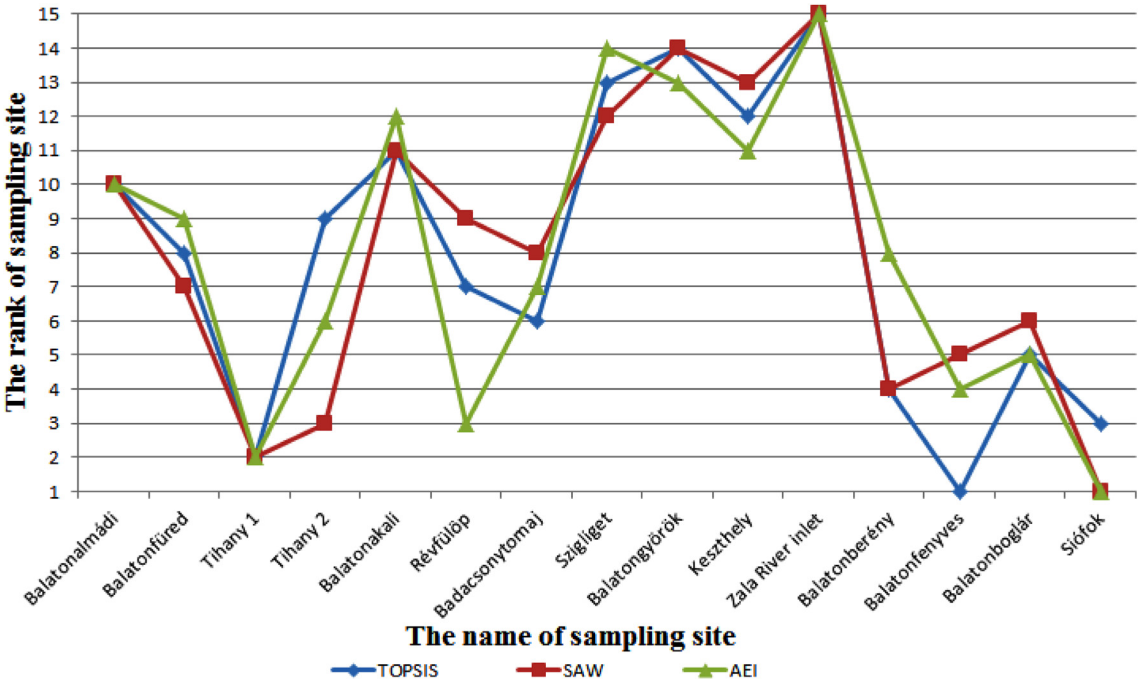

Fig. 6. Comparison of the results of the water quality evaluation methods.

showed in Fig. 3, sites 8, 9, 10, 11, and 12 have different water quality compared to other sampling sites that are located in the Keszthely and Szigliget basins. The AEI value was weak (10.00 ≤ A EI < 16.67), mainly in site 11, indicating that this site was polluted due to direct contamination of water with nutrients and other chemicals from nearby agricultural activities and the load of Zala River (Némethy and Molnár, 2014). The latter carries about half of the pollution load into Lake Balaton (Kutics, 2019). Dissolved oxgen values were higher than the threshold foudn in all sampling sites, excepting site 11 and 12, where the concentrations were 1.44 and 6.98 mg/L, respectively. A critically low DO value was observed in site 11, which can cause serious effects on aquatic life. As proven by Wang et al. (2019), DO values show a healthy aquatic life if between 4 and 6 mg/L. The most important parameters measured in the current study indicate negative impact on lake water quality of the lake as induced by the nutrients load (i.e., N and P compounds). These nutrients inhence cyanobacteria and are resposible for algal blooms, which is a direct consequence of eutrophication. This is considered a favourable conditions of high level nutrients, which is necessery for Zooplankton growth (Saler and Selamoglu 2020).

The main cause of eutrophication is the excessive nitrogen and phosphorus enrichment (Zhang et al., 2017, Pacioglu and Moldovan, 2016). The eutrophication process and algal blooms remain of majorenvironmental concern for global waterissues, which are not only adversely impacted by local ecosystems but also pose potential risks to public health (Häder et al., 2020, Pacioglu et al. 2016). The lower recorded NO_3-N concentrations were indicated in the results due to the denitrification of NO_3-N into N_2 under anaerobic conditions, which mitigates the nitrate concentration in water bodies, the latter being released into the atmosphere (Lin et al., 2020, Pacioglu & Pârvulescu, 2017). Only about 20% of the input of nutrients is absorbed and transformed into protein by aquatic biota,the remaining being cycled in water or settling into sediments, forming endogenous pollutants (Ni et al., 2016). Thechemical and biological oxygen demands provide

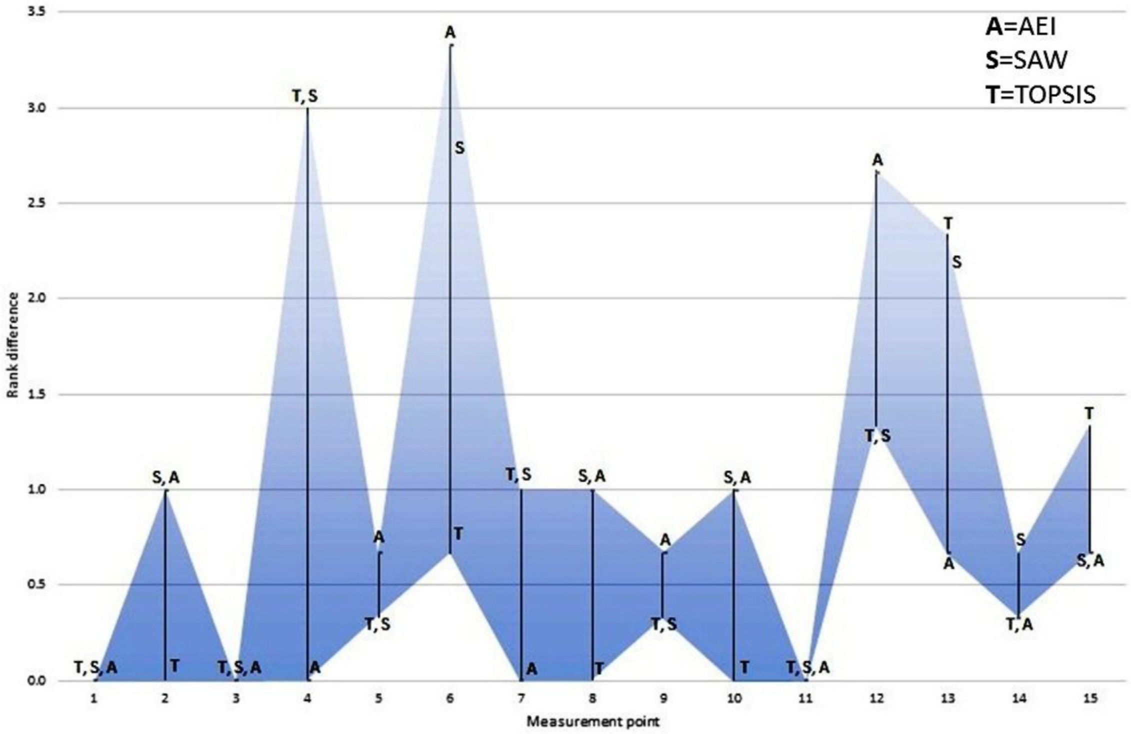

Fig. 7. Comparison of the results of the water quality evaluation methods based on the sum of ranking differences approach.

information on the organi load in water (Bayard et al., 2018). The results indicated that both COD and BOD_5 concentrations were higher than the threshold values at site 11 (4 and 43.25 mgL, respectively). The contaminated part of the lake is represented by the western part of the water body due to the runoff agricultural chemicals which come via Zala River inlet straight into the lake. The higher value of COD is directly related to BOD_5. The increase in BOD_5 concentrations at site 11 is due to the organic matters stemming from the respiration of plankton and bacteria in the lake (Smagin et al., 2018), potentially inducing high mortality among fish, corroborated with low oxygen concentration (Kandemir et al., 2010).

The Draining of extensive marshlands and rivers embankments (mostly Zala River, the largest tributary of the lake) certainly had one serious consequence, by accelerated the silting process of the lakebed, especially in the south-western part (Kutics, 2011), with detrimental effects on sediment dwelling fauna (Pacioglu et al. 2012). However, given that the pollutant and nutrient load of the tributaries must have been low, the water quality did not decrease. The lowering of the water level during the period when the current study was undertaken by approximately 3 m led to the practical disappearance of the hypolimnion, increased sediment resuspension and increasing sensitivity to changes in the hydrometeorological conditions (Szigedi et al., 2013). The anthropic impacts are present and the remediation possibilities are limited. In conclusion, the mitigation techniques and measures to be taken are requested for the future (Kertész, 2011), as the financial implications. Moreover, the average value of AEI for whole lake was 22.13 and considered as proper water quality class ($16.67 \leq AEI < 23.33$), implying that the water of the Lake Balaton is moderately polluted and the anthropogenic impacts present.

The results illustrate that the Siófok area the least polluted site on the lake, according to the AEI and SAW assessment methods (Figs. 3 and 5), whereas according to the TOPSIS (Fig. 4.), the Balatonfenyves area was the least polluted site, demonstrating that all assessment methods are congruent with Zala River inlet area as the most polluted site.

The results showed that the value obtained from the AEI analysis method was the same as the mean value between TOPSIS and SAW methods (Figs. 6 and 7). Therefore, by using all three quantitative methods, a more comprehending understanding of the water quality is obtained.

The results highlightthe need for proper implementation of methods for these crucial environmental issues and suggest multiple solutions and management practices, which can be applied through cooperation with the governmental policies to restore eutrophic impaired lakes and improving the water quality (Pacioglu et al. 2016). One of the potentials for aeration problems is by using Oxygen-carrying materials (OCM) which comprise modified natural zeolites. They are used as capping agents and oxygen-locking layer in anoxic conditions of lakes. The result is an increasing DO content from 1.5 mg/L to 3.5–4 mg/L, as reported previously by Zhang et al. (2020).

Specifically, several management practices proved to be efficiencient for phosphorus removal, such as the use of biofilters, bio-retention, detention basins, porous pavements, wetland basins, and dry ponds (Osgood, 2017, Caen et al., 2019). Geoengineering techniques were employed to control phosphorus load and cyanobacteria in eutrophic lakes, as promising greater and faster chemical and ecological recovery techniques by using coagulants such as aluminium sulphate, polyaluminium chloride and chitosan alone and combined with natural bentonite clays to remove of phosphorus from the eutrophic Lakes (Lucena-Silva et al., 2019). Physical (Hypolimnetic withdrawal method and Macrophyte harvest), chemical (Phosphate binder and Copper-based algaecides) and biological (Effective micro-organisms and Dreissenids) mitigation methods were applied to reduce nutrients load (Lürling and Mucci, 2020). Several promising treatments were investigated, such as the phytoremediation removal techniques in lakes to reduce the nutrient load. This ecological restoration can be accomplished through aquatic plants that compete with algae for light, nutrients and space and that use the stored nutrients in the vegetal tissues (Ngatia and Taylor, 2018).

5. Conclusions

The primary objective of using different environmental impact assessment methods in this work was to determine the state of water quality in Lake Balaton. TOPSIS & SAW methods output correlated closely to the result of analysing water quality parameters. Based on the rankings of those methods, another finding was that water quality needs to be improved in the western part of the lake by employing suitable geoengineering treatment techniques. Therefore, this technique can be used by environmental managers to make decisions easy, whenever facing the implications of several complicated parameters. Conducting a water quality assessment is mandatory for environmental managers in order to identify vulnerabilities within lake ecosystems, and future plans are needed to upgrade water quality standards. TOPSIS and SAW methods proved to be useful for ranking various sampling sites situated along the lake; however, the practicality of the AEI method was limited to one site. The further applications of TOPSIS-based approaches become increasingly popular among the routine water quality assessment techniques. Nevertheless, the number of studies that considered the correlations among water quality indicators or that coupled them with water quality standards in a reasonable manner is scarce. The major difference in MCDM evaluation methods and the AEI assessment method is that the contribution of WQI classes was omitted in the calculation of the MCDMs. The ranking method based on SRD criteria uses a part of overlooked information overlooked and corresponds to the principle of parsimony, providing an easy way to rank methods.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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