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RECENT ADVANCES IN CHEMISTRY AND THE ENVIRONMENT

Methodology development on aquatic environmental assessment

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Abstract The Water Framework Directive aims at reaching the good ecological status of the surface and ground water bodies (László et al. Microchem J 85(1):65–71, 2007). The paper deals with quality evaluation of waters with special focus on the water chemistry parameters as defined in the Water Framework Directive and pertaining legal regulations. The purpose of this paper is to devise a quantitative type of water quality assessment method which could provide rapid, accurate, and reliable information on the quality of the surface waters by using water chemistry parameters. Quality classes have been defined for every water chemistry parameter in light of the legal limit values of the water parameters. In addition to this, weight indices were calculated on the basis of the outcome of the paired comparison of water chemistry parameters and normalized matrix. This was followed by the parametric level analysis of the water chemistry parameters, and finally, the aquatic environment index (AEI) was calculated, which provided general information on the quality of water regarding the water chemistry parameters. The method was illustrated on Lake Balaton, Hungary in which case water samples taken from Balatonfüred City lake area were analyzed and evaluated with the method devised.

Keywords Evaluation algorithm · Physical-chemical parameters · Surface water · Water quality · Lake Balaton

Nomenclature

A, B, C, D, E, F, G, H, I	Empirical constants
AEA	Aquatic environmental assessment
AEI	Aquatic environment index
AHP	Analytical hierarchy process
ANFIS	Adaptive neuro-fuzzy inference system
AQUATOX	Aquatic ecosystem simulation model
BOD	Biological oxygen demand
Chla	Chlorophyll a
C_i	Average figures of the rows in the normalized matrix
C_{Lvi}	Limit value of water chemistry parameter i
C_{Mi}	Measured value of water chemistry parameter i
COD	Chemical oxygen demand
DO	Dissolved oxygen
e	Euler number
EC	Electrical conductivity
EIA	Environmental impact assessment
GD	Governmental decree
GIS	Geographic information system
MCDM	Multi-criteria decision making
MSZ	Hungarian standards
n	Number of the water chemistry parameters
QC_i	Quality class of water chemistry parameter i

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Q_{Di}	Deviation of water chemistry parameter i from the legal limit value
RIAM	Rapid impact assessment matrix
OS	Oxygen saturation
TN	Total nitrogen
TOPSIS	Technique for Order Preference by Similarity System
TP	Total phosphorus
TU	Turbidity
WFD	Water Framework Directive
WI	Weight index
X_{QC}	Quality class of water chemistry parameter i
y	Concentration of water chemistry parameter i

Introduction

The state of the environment has been deteriorated in extremely high extent due to economic and industrial activities, continuous pollution of the environment, exploitation of the natural resources, and drastic growth of the population and due to several other factors (Robu 2005). The nations of the world have committed themselves to make preventive measures and actions in order to slow down, stop, and—if possible—reverse this disadvantageous and harmful process. Common actions were requested to cope with the global and regional environmental issues. Harmonization was needed in legal regulations to guarantee the efficiency of the preventive measures in order to mitigate the environmental problems. The environmental impact assessment was a procedure which aims to analyze and evaluate the impacts of the human activity on the environment (Rédey et al. 2002). In this way, it supports the actions for the improvement in the environmental quality and helps the practical implementation of the sustainable development (Toro et al. 2013). The environmental impact assessment is an efficient tool to make preliminary evaluation on the environmental impacts of different actions, projects, and investments (Utasi et al. 2013). Since the water is a distinguished environmental element and the protection of the surface waters and underground waters is of vital importance, therefore the evaluation of the water quality and the follow-up of the changes in water quality are indispensable tools for future actions that will be implemented.

The quality control and the continuous monitoring of the surface waters and the assessment of the data obtained are outstanding goals in the Water Framework Directive (WFD 2000). There are several methods to carry out environmental impact assessment procedure. The checklists, the matrix technique, the networking, the GIS methods, and the quantitative methods can be used to evaluate the environmental impacts and to reach a final conclusion (Canter 1996). It is to be emphasized that there is no distinguished or unique method. The user should decide which methods are to be used in the procedure. Since there is an increasing pressure to numerically express the environmental impacts, the quantitative methods have been considered to be beneficial methods since those are capable to compare different project alternatives as well. The multi-criteria decision making (Hwang and Yoon 1981) method, analytical hierarchy process (Saaty 2008), and the Technique for Order Preference by Similarity Systems (TOPSIS) (Herva and Roca 2013) can be used as well to support the decision making.

Modeling techniques can be used for the assessment of the surface waters, e.g., the AQUATOX model (Akkoyunlu and Karaashan 2015) uses conventional parameters such as dissolved oxygen, temperature, total suspended solids, pH, total nitrogen, total phosphorus, and labile and refractory organic matters in water and sediments to evaluate the quality of the waters.

Among the quantitative environmental impact assessment methods, the Battelle-Columbus method (Dee et al. 1972; Battelle Memorial Institute. Columbus Laboratories 1972) also should be mentioned in which case an environmental impact unit is defined on the basis of the environmental quality index and environmental parameter importance unit. The quantitative methods define a numerical value which quantifies the status of the environment (Glasson 1995). There are other methods as well, e.g., the quantitative method developed by Robu et al. (2005) and Utasi (2015). These quantitative methods can be used to evaluate the quality of the environment in a complex way and are suitable for the evaluation of the impacts of the human activities to the environment (Zaharia 2012) as well as to elaborate mitigation plans for the rehabilitation of the polluted environment (Stefănescu et al. 2013).

The main objective of the work was to develop a quantitative aquatic environmental assessment (AEA) method suitable for the qualitative evaluation of surface and ground water bodies. An example of the use of the new method is given in the paper based on the measured water physical-chemical data of Lake Balaton in the Transdanubian region of Hungary. It is planned to utilize this method in further monitoring on the water quality of Lake Balaton in order to have a comprehensive picture on the water quality of the Lake Balaton. The relationship of water quality parameters can be analyzed with Pearson product-moment correlation analysis or Partial correlation analysis (Mustapha et al. 2013).

The abovementioned environmental impact assessment methods are specified to deal with the whole environment including the environmental elements and environmental systems. The quality of the surface water is a key issue in our days. The surface and underground waters are very sensitive for the pollution and since the waters are recipients in several ways of the pollution discharges, e.g., wastewaters, soil erosion, human activities, the maintenance and upgrading of the water quality have high priority (Khan et al. 2015).

Our objective was to focus only on one environmental element, the water, namely on the surface water and to devise a quantitative environmental assessment method for the water in harmony with European Union guidelines and Water Framework Directive (Directive of the European Parliament and of the Council 2000/60/EC). The assessment of the water quality is a major issue in the long term security of the water supply.

Several methods have been developed during the past several decades for the assessment of the water quality; however, these methods require resetting and calibration prior to be used in a new field. It would be beneficial if the assessment of the quality of the water body could be accomplished in an easy and customized way (Yu et al. 2015).

The quantitative methods have been in use in wide scale. Those are used for mitigating environmental problems based on environmental impact analysis and to devise strategic environmental plans. The outcome could be used for future actions to be implemented to improve the quality of the water, as it happened in the case of Three Gorges Reservoir Area (Huang et al. 2015).

The quantitative method, namely the rapid impact matrix has been used in case of wind mills in UK to quantify the expected environmental impacts (Phillips 2015).

Experimental

According to the Water Framework Directive, the biological/ecological, hydromorphological, physical-chemical parameters, other contaminations, and priority parameters are to be considered for the quality evaluation of the waters. In this paper, only the physical-chemical parameters (hereinafter also referred to as water chemistry parameters) are under investigation. However, it is to be noted that the other categories (biological/ecological, hydromorphological, etc.) will be dealt later in a separate paper. The current goal of the paper was to elaborate a method for the comprehensive evaluation of the physical-chemical (water chemistry) parameters of the waters and to illustrate its usability on the Lake Balaton.

Lake Balaton is the largest lake in Hungary (Istvánkovics et al. 2007). It is 17,000–19,000 years old (Cserny and Nagy-Bodor 2000) and located in west Hungary. Its watershed area is 5800 km^2, the length of the lake is 77 km, and the average depth of the lake is 3.25 m. The surface of water is 596 km^2 (Polyák and Hlavay 2005). Lake Balaton is a distinguished touristic destination in Hungary, and the lake plays an important role in the water supply as well. It provides 9 million t of raw water for use. Therefore, the continuous monitoring of the water of the Lake Balaton is very important. Therefore, water samples were taken at different locations at Lake Balaton.

The quality of the water of Lake Balaton was studied at 10 locations around the lake. However, this paper discusses the water analytical results taken at Balatonfüred on the northern shore of the lake. The analytical results of all locations will be discussed in a separate paper. The water samples were taken at Balatonfüred at the following geographical coordinates, 46° 57.215′ N and 017° 53.704′ E, and elevation 107 m above Baltic Sea level.

The samples were taken 70 m from the shore at a depth of 0.5 m according to the Hungarian Standard MSZ ISO 5667–4:1995. Four liters of water was taken which was put into an air tight sample holder. The samples were analyzed at site and were taken to laboratory for further studies. The following parameters were measured at site according to Hungarian Standards (MSZ) with the instruments indicated in parentheses:

1. Chlorophyll a (TRIOS (MicroFlu-chl) online UV-fluorescent measuring probe
2. pH (NEOTEK PONSEL Digital sensor PHEHT: pH, Redox, Temperature, Datasheet)
3. Dissolved oxygen content, oxygen saturation (NOETEK-PONSEL Digital sensor: ODOT: Optical Dissolved Oxygen Datasheet) MSZ EN ISO 7027:2000
4. Specific conductivity (NOETEK-PONSEL Digital sensorC4E: Conductivity/Salinity Datasheet) MSZ 448-32:1977
5. Turbidity was measured according to (NEOTEK-PONSEL Digital sensor C4E: Turbidity Datasheet) MSZ EN ISO 7027:2000
6. pH was measured according to MSZ 1484-22:2009

The following water chemistry parameters were measured at the laboratory of the Institute of Environmental Engineering, University of Pannonia according to the MSZ:

1. COD$_{cr}$, MSZ ISO 6060:1991
2. BOD$_5$, MSZ EN 1899-2:2000
3. Phosphate ion and total phosphorus content, MSZ 448-18:2009 ammonium content, MSZ ISO 7150-1:1992
4. Nitrate content, MSZ 260/11-71
5. Total nitrogen content, MSZ 12750-20:1972.

Results and methodology

Table 1 includes the measurement results on the water and the limit values for the surface water body of Lake Balaton according to the Governmental Decree No. 10/2010. (VIII. 18) of Ministry of Regional Development (GD 2010).

On the basis of classification of the Governmental Decree No. 31/2004. (XII. 30.) of Ministry of Environment and Water

Table 1 Physical-chemical parameters of the water of Lake Balaton at Balatonfüred site

Parameter	Measured value	Limit value	Quality category
Chlorophyll a, µg/l	2.84	<15.00	Excellent
Turbidity[a], NTU	14.30	–	Good
pH_{acidic}	–	7.80	–
$pH_{alkaline}$	8.73	9.20	Good
Conductivity, µSv/cm	773.90	<800.00	Proper
Dissolved oxygen, mg/l	10.89	7.50–10.50	Excellent
Oxygen saturation, %	106.91	80.00–120.00	Excellent
BOD_5, mg/l	0.50	<2.50	Excellent
COD_{cr}, mg/l	16.58	<30.00	Excellent
NH_4-N, mg/l	0.02	<0.05	Excellent
NO_3-N, mg/l	0.52	<0.06	Bad
Total N, mg/l	0.63	<1.40	Excellent
PO_4-P, mg/l	0.02	<0.01	Bad
Total P, mg/l	0.05	<0.12	Excellent

[a] The limit value of the turbidity was taken on the calibration set of the measurement standard

(GD 2004), there are 25 rivers and 17 stagnant water types in Hungary. The Lake Balaton is characterized as open water surface of large area having moderate depth and lime-water type.

Table 1 includes the measurement results and the limit values on the water of Lake Balaton sampled at Balatonfüred. The values indicated in Table 1 as measured values are the average values of three parallel measurements.

It was our objective to devise an aquatic assessment algorithm, which is based on the methodology of the environmental impact assessment and which focuses only on the aquatic environment from the chemistry point of view. In order to evaluate the chemistry of the aquatic environment, the water chemistry parameters are taken into consideration in the present paper.

Figure 1 illustrates the algorithm of the method. The second step of the new method is the classification of the water body in

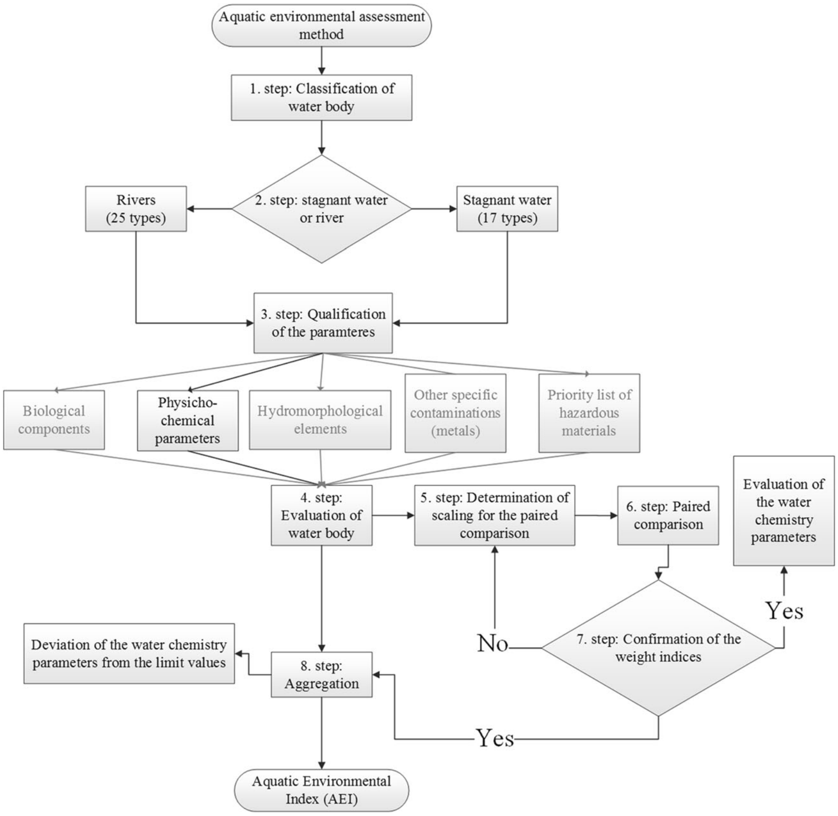
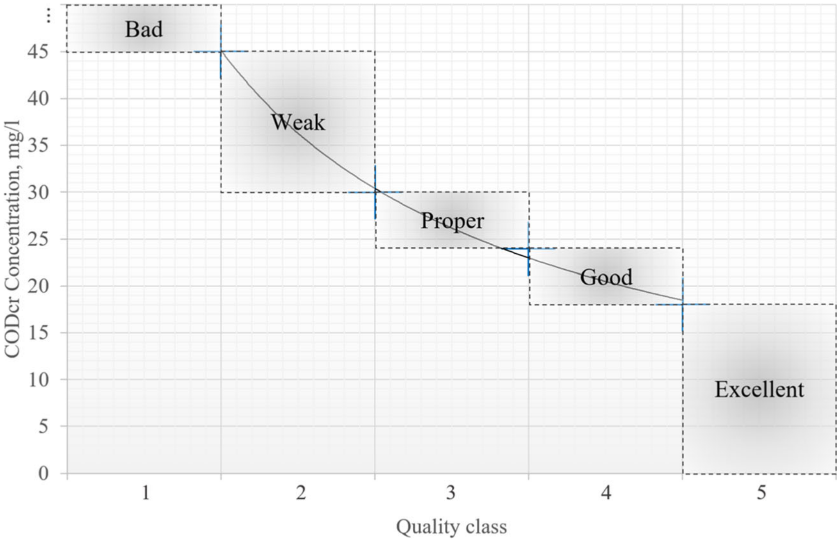


Fig. 1 Algorithm of the procedure of aquatic environmental assessment method

Fig. 2 First type of functional relationship, namely, for the determination of chemical oxygen demand quality class



harmony with the Hungarian and European Union requirements. The typology of the water body under investigation should be determined and this is followed by the determination of the legal limit values for the water chemistry parameters (GD 2004; GD 2010). The legal limit value depends on the water body, namely, if it is a stagnant water or river water. Following the classification of the water body, the legal limit values can be given on the basis of the pertaining environmental regulations.

The quality assessment of the water chemistry parameters is carried out on the basis of the measured values and the limit values of the parameters defined in national regulations and specifications for the surface waters. The figures are summarized in an evaluation table (Table 6). On the basis of the measured water chemistry parameters and legal limit values of the national regulations and specifications, the quality class can be determined for the given environmental/water chemistry parameter according to an algorithm defined in the following. It is to be emphasized repeatedly that only water chemistry parameters/physical-chemical parameters are considered within the scope of the present paper.

However, the method can be developed in a modular way, and according to the demands and requirements, several additional parameter sets can be included in the study, e.g., parameters on biological status, hydromorphological features, other specific contaminations, and priority list of the waters as it can be seen in Fig. 1.

The figures of the quality classes obtained during the procedure will be used in the following steps. According to the conventional method, the assessment can be carried out without individual weights for the water chemistry parameters and all parameters can be considered to have equal importance.

However, the outcome of the evaluation could be more precise and more informative if individual weights were defined and assigned for the water chemistry parameters. At first, importance factors were defined for the paired comparison of the water chemistry parameters. In order to establish the importance weights, the paired comparison is carried out for all combinations of the water chemistry parameters. For the determination of the importance factor, the method defined in the literature (Canter 1996) was followed. The importance factors can be a subject of a professional confirmation as well in light of the water body under study.

The categorization of water bodies had been carried out until 2010 in Hungary according to the Water Framework Directive of the European Union. Therefore, the first three steps of the procedure can be carried out based on the data bases. The steps that need to be taken are as follows: categorization of the water body, stagnant water or river (first decision point). The determination of the type of the water body has been carried out up to this point. In our case, the water considered is a lake, namely, the Lake Balaton.

The next step is the quality evaluation of the water chemistry parameters (Fig. 1, step 4). The measured water

Table 2 The empirical constant values of Eq. (1)

Water chemistry parameter	Chlorophyll a	Conductivity	BOD_5	COD_{cr}	NH_4-N	NO_3-N	Total N	PO_4-P	Total P
Empirical constant (A)	44.33	2364.20	7.39	88.66	0.15	0.18	4.14	0.03	0.36
Empirical constant (B)	−0.97	−0.97	−0.97	−0.97	−0.97	−0.97	−0.97	−0.97	−0.97

chemistry parameters and the legal limit values for the surface water according to the type of the surface water are summarized in Table 1.

For every water chemistry parameter, a functional relationship has to be defined. Quality classes and categories are defined from 1 (bad) till 5 (excellent). The ranking of the measured water chemistry parameters have to be carried out based on the value relationship, namely on the basis of the change of the water chemistry parameters in the function of quality classes from 1 to 5.

A functional relationship had been set up for all water chemistry parameters studied. The limit values of the water body—in this case Lake Balaton—were taken from the national regulations, and these figures were identified as the upper limit of the bad quality classes, namely, quality class no. 1. The other quality classes (weak (no. 2), proper (no. 3), good (no. 4), excellent (no. 5)) were determined in the percentage value of the limit value given in the national regulations. The quality classes represent an interval, e.g., in case of chemical oxygen demand (COD) concentration, the bad quality class (quality class no. 1) represents COD values equal to and higher than 45 mg/l. as it can be seen in Fig. 2. Mathematical fitting was used to set up functional relationships between the measured water chemistry parameters and the quality classes. The functional relationships of 13 water chemistry parameters can be categorized into four types of functional relationships as specified below. The first type is power function type which refers to chlorophyll a, conductivity, BOD_5, COD_{Cr}, NH_4-N, NO_3-N, total nitrogen, and PO_4-P (Eq. (1); Table 2). The second type of the functional relationship can be described by second-degree equation, e.g., for dissolved oxygen content (Eq. (2); Table 3). The third type of functional relationship is an exponential type, e.g., for the turbidity (Eq. (3); Table 4). The fourth type of the functional relationship is the linear relationship (Eq. (4); Table 5).

$$x_{QC} = A \times y^{B} \tag{1}$$

where x_{QC} is the quality class of water chemistry parameter; y is the concentration of water chemistry parameter; and A and B are empirical constants. The values of these constants are indicated in Table 2. The regression value of Eq. (1) is 0.9937 for the water chemistry parameters of type 1.

Table 3 The empirical constant values of oxygen parameters

Water chemistry parameter	Dissolved oxygen	Oxygen saturation
Empirical constant (C)	−0.14	−1.50
Empirical constant (D)	2.02	21.70
Empirical constant (E)	2.59	27.50

Table 4 The empirical constant values of Eq. (3)

Water chemistry parameter	Turbidity
Empirical constant (F)	488.97
Empirical constant (G)	−0.78

Figure 2 indicates the functional relationship for the COD. The y-axis indicates the COD values, and the x-axis shows the quality classes. On the basis of Fig. 2, the quality class of the water can be determined for COD using the analytical data. The measured data for COD is 16.58 mg/l, the limit value is 30 mg/l (Table 1), and this way, the quality class is 5, the quality category is excellent (Tables 1 and 6). Similar technique was used for the determination of the quality classes for biological oxygen demand (BOD), conductivity, etc. as mentioned above.

Similarly, a functional relationship can be given for the dissolved oxygen as well (Fig. 3). The dissolved oxygen in milligram per liter is defined in function of the quality classes. If the dissolved oxygen of the water is higher, it means better water quality from the point of view of the oxygen content of the water. Quality class 1 (bad quality category) represents a dissolved oxygen below 6 mg/l. Quality class 2 (weak quality class) shows a dissolved oxygen between 6 and 7 mg/l. Quality class 5 (excellent quality category) indicates a dissolved oxygen content above 9 mg/l.

$$x_{QC} = C \times y^{2} + D \times y + E \tag{2}$$

where x_{QC} is the quality class of water chemistry parameter; y is the concentration value of water chemistry parameter, dissolved oxygen; and C, D, and E are empirical constants. The values of these constants are indicated in Table 3. The regression value of the dissolved oxygen parameters in Eq. (2) is 0.9982.

In a similar way, a functional relationship can be defined for the turbidity as well (Fig. 4). An exponential curve can be given for the turbidity as it is shown in Fig. 4.

$$x_{QC} = F \times e^{G \times y} \tag{3}$$

Table 5 The empirical constant values of Eq. (4)

Water chemistry parameter	pH_{acidic}	$pH_{alkaline}$
Empirical constant (H)	0.50	−1.00
Empirical constant (I)	4.50	12.00

Table 6 Determination of the quality classes of water chemical parameters of Lake Balaton at Balatonfüred

Physical-chemical parameters						
Parameter	Measured parameter	Quality classes QC_i and categories				
Quality class		1	2	3	4	5
Quality category		Bad	Weak	Proper	Good	Excellent
Chlorophyll a, µg/l	2.84	>22.50	22.50	15.00	12.00	<9.00
Turbidity[a], NTU	14.30	>100.00	100.00	50.00	20.00	<10.00
pH_{acidic}[a]	–	<5.00	5.50	6.00	6.50	7.00
$pH_{alkaline}$[a]	8.73	>11.00	10.00	9.00	8.00	7.00
Conductivity, µSv/cm	773.9	>1200.00	1200.00	800.00	640.00	<480.00
Dissolved oxygen, mg/l	10.89	<6.00	6.00	7.50	8.45	>9.38
Oxygen saturation, %	106.91	<64.00	64.00	80.00	90.00	>100.00
BOD_5, mg/l	0.50	>3.80	3.80	2.50	2.00	<1.50
COD_{cr}, mg/l	16.58	>45.00	45.00	30.00	24.00	<18.00
NH_4-N, mg/l	0.02	>0.075	0.075	0.05	0.04	<0.03
NO_3-N, mg/l	0.52	>0.09	0.09	0.06	0.05	<0.04
Total N, mg/l	0.63	>2.10	2.10	1.40	1.12	<0.84
PO_4-P, mg/l	0.02	>0.015	0.015	0.01	0.008	<0.006
Total P, mg/l	0.05	>0.18	0.18	0.12	0.096	<0.072

[a] The turbidity intervals were defined according to the calibration set of the measurement standard. The pH intervals were established according to the Hungarian conditions

where x_{QC} is the quality class of water chemistry parameter; y is the concentration value of water chemistry parameter; and F and G are empirical constants. The values of these constants are indicated in Table 4. The regression value for the turbidity in Eq. (3) is 0.9968.

In case of the pH acidic and caustic ranges can be distinguished. Therefore two separate relationships have been defined as shown in Fig. 5. Linear relationships are given and those intercept each other at pH = 7.0.

$$x_{QC} = H \times y + I \tag{4}$$

where x_{QC} is the quality class of water chemistry parameter, pH; y is the concentration value of water chemistry parameter,

Fig. 3 Second type of functional relationship, namely, for the determination of the dissolved oxygen quality class

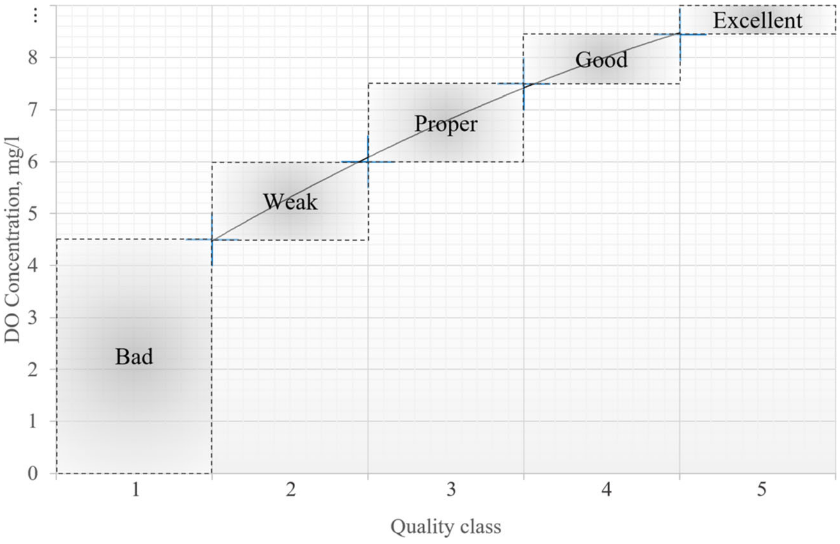
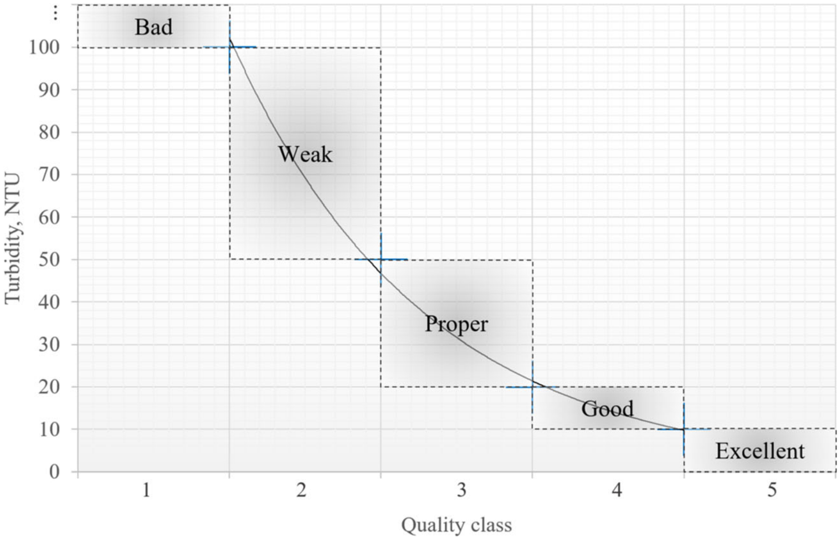


Fig. 4 Third type of functional relationship, namely, for the determination of the turbidity quality class



pH; and H and I are empirical constants. The values of these constants are indicated in Table 5. The regression value of Eq. (4) is 1.0000.

The determination of the quality classes of the water chemistry parameter can be done on the basis of the measurement results and the abovementioned functional relationships and those are summarized in Tables 1 and 6. It is to be noted repeatedly that the determination of the quality classes and categories is based on the actual measurement results and the limit values of the national specifications and regulations as mentioned before.

The heading of the base table (Table 6) shows five quality classes (1, 2, 3, 4, and 5) for which quality categories are assigned (bad-excellent). The quality classes indicate improving condition in the water chemistry parameter from left to right. It means that the quality class 1 indicates the worst case, while the increasing numbers until 5 indicate improving conditions in the water. In case of each water chemistry parameter, a parameter interval can be assigned for each quality class which supports the ranking of the measured water chemistry parameter (Table 6). This interval is defined for each water chemistry parameter. The interpretation of the interval is explained below.

Quality class no. 1 represents a situation when the water chemistry parameters for the pollutants are present in high concentration. In case of BOD, if the measured value is above 3.8 mg/l, then the figure should be ranked into quality class no. 1. From environmental and water quality

Fig. 5 Fourth type of functional relationship for the determination of the pH quality class

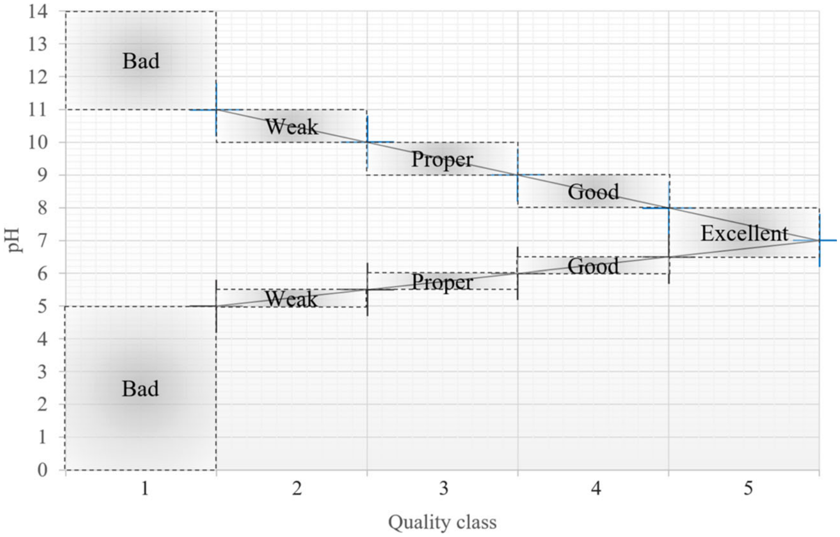


Table 7 Scaling for the paired comparison (Saaty 1988)

Basic scale to the paired comparison		
Numerical figure of the importance	Meaning	Explanation
1	Equal importance	There is no significant difference between the water chemistry parameters studied
3	Moderate importance	One of the parameters of the water chemistry parameters has slightly higher importance
5	Strong importance	One of the parameters of the water chemistry parameters has higher importance
7	Very strong importance	One of the parameters of the water chemistry parameters has significantly higher importance
9	Extreme high importance	One of the parameters of the water chemistry parameters has significantly higher importance

points of view, the situation is just the opposite in case of dissolved oxygen. If the concentration of the dissolved oxygen is lower, this means a worse water quality. It can be seen in Table 6 that if the dissolved oxygen concentration is below 6.0 mg/l, then the figure should be ranked into category class no. 1.

Quality class no. 2 shows a slightly better case in comparison with case no. 1. In case of BOD, this represents a concentration range of 2.5–3.8 mg/l. If the measured BOD concentration is within this range, then the measured figure should be ranked into this quality category.

Quality class no. 3 represents a moderate case. In case of BOD, this represents a concentration range of 2.1–2.5 mg/l. The upper limit of the quality class no. 4 is 2.0 mg/l in case of BOD. The lower limit is 1.5 mg/l which represents good water quality from the point of view of BOD (Table 6).

Quality class no. 5 represents an excellent water quality when the pollutant water chemistry parameters are present in low concentration and the dissolved oxygen and oxygen saturation are higher in comparison with the limit value. In Table 6, for quality class no. 5, only the upper limit of the pollutants is indicated except for the dissolved oxygen and oxygen saturation where the lower limit is given. In case of dissolved oxygen, if the measured value is higher than 9.38 mg/l, then the oxygen content should be ranked into quality class no. 5.

Quality assessment of the water chemistry parameters

During the assessment, the data summarized in Table 6 for the water sample taken from Lake Balaton at Balatonfüred are dealt with. The measured water chemistry values are ranked according to the principles given above into different quality classes as indicated in Table 6. The measured water chemistry parameters are ranked as the shaded places indicate in Table 6. The shaded figures in Table 2 indicate the places for the qual-

Table 8 Basic matrix of paired comparison of the water chemistry parameters

Weighting	Chl*a*	TU	pH	EC	DO	OS	BOD$_5$	COD$_{cr}$	NH$_4$-N	NO$_3$-N	Total N	PO$_4$-P	Total P
Chl*a*	1.00	2.00	0.33	0.50	0.17	0.17	0.20	0.14	0.25	0.25	0.14	0.11	0.11
TU	0.50	1.00	0.25	0.33	0.14	0.14	0.17	0.13	0.20	0.20	0.13	0.11	0.11
pH	3.00	4.00	1.00	2.00	0.33	0.33	0.50	0.25	0.50	0.50	0.25	0.17	0.17
EC	2.00	3.00	0.50	1.00	0.25	0.25	0.33	0.20	0.50	0.50	0.20	0.14	0.14
DO	6.00	7.00	3.00	4.00	1.00	1.00	2.00	0.50	3.00	3.00	0.50	0.33	0.33
OS	6.00	7.00	3.00	4.00	1.00	1.00	2.00	0.50	3.00	3.00	0.50	0.33	0.33
BOD$_5$	5.00	6.00	2.00	3.00	0.50	0.50	1.00	0.33	2.00	2.00	0.33	0.25	0.25
COD$_{cr}$	7.00	8.00	4.00	5.00	2.00	2.00	3.00	1.00	3.00	3.00	1.00	0.50	0.50
NH$_4$-N	4.00	5.00	2.00	2.00	0.33	0.33	0.50	0.33	1.00	1.00	0.33	0.20	0.20
NO$_3$-N	4.00	5.00	2.00	2.00	0.33	0.33	0.50	0.33	1.00	1.00	0.33	0.20	0.20
Total N	7.00	8.00	4.00	5.00	2.00	2.00	3.00	1.00	3.00	3.00	1.00	0.50	0.50
PO$_4$-P	9.00	9.00	6.00	7.00	3.00	3.00	4.00	2.00	5.00	5.00	2.00	1.00	1.00
Total P	9.00	9.00	6.00	7.00	3.00	3.00	4.00	2.00	5.00	5.00	2.00	1.00	1.00
Sum	*63.50*	*74.00*	*34.08*	*42.83*	*14.06*	*14.06*	*21.20*	*8.72*	*27.45*	*27.45*	*8.72*	*4.85*	*4.85*

Table 9 Normalized matrix for the water chemistry parameters

	Chl*a*	TU	pH	EC	DO	OS	BOD_5	COD_{cr}	NH_4-N	NO_3-N	Total N	PO_4-P	Total P
Chl*a*	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02
TU	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
pH	0.05	0.05	0.03	0.05	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.03	0.03
EC	0.03	0.04	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
DO	0.09	0.09	0.09	0.09	0.07	0.07	0.09	0.06	0.11	0.11	0.06	0.07	0.07
OS	0.09	0.09	0.09	0.09	0.07	0.07	0.09	0.06	0.11	0.11	0.06	0.07	0.07
BOD_5	0.08	0.08	0.06	0.07	0.04	0.04	0.05	0.04	0.07	0.07	0.04	0.05	0.05
COD_{cr}	0.11	0.11	0.12	0.12	0.14	0.14	0.14	0.11	0.11	0.11	0.11	0.10	0.10
NH_4-N	0.06	0.07	0.06	0.05	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.04	0.04
NO_3-N	0.06	0.07	0.06	0.05	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.04	0.04
Total N	0.11	0.11	0.12	0.12	0.14	0.14	0.14	0.11	0.11	0.11	0.11	0.10	0.10
PO_4-P	0.14	0.12	0.18	0.16	0.21	0.21	0.19	0.23	0.18	0.18	0.23	0.21	0.21
Total P	0.14	0.12	0.18	0.16	0.21	0.21	0.19	0.23	0.18	0.18	0.23	0.21	0.21

ity classes. For example, in case of chlorophyll a, the measured value is 2.84 μg/l, which indicates an assignment into the quality class no. 5 since the measured value is lower than 9.0 μg/l.

Following this, the quality classes determined for all water chemistry parameters will be used for the further assessment procedure.

The next step is the determination of the weight index for all water chemistry parameters. This will be accomplished by paired comparison of the water chemistry parameters and normalization. However, the first step is to set up a basic scale for the paired comparison of the water chemistry parameters as given in the literature (Canter 1996).

Table 7 includes the basic scaling of the paired comparison which is used for the evaluation of the functional relations. However, it is to be noted that the numerical figure of the importance can have intermediate values as well (e.g., 2, 4, etc.) depending on the outcome of the paired comparison of the water chemistry parameters. These importance factors quantify the relations among the individual parameters. The evaluation should be carried out according to rows. The water chemistry parameter given in the row should be related to the water chemistry parameters given in the columns by using the scaling given in Table 7. It is carried out as follows: the parameter of the first row is related to the parameter of the first column. In Table 8, this means that the chlorophyll a is related to chlorophyll a which means that the parameters are equally important. This is marked by 1.00 in the matrix (Table 8). The next parameter in the column is the turbidity, which is related to chlorophyll a. In comparison of the chlorophyll a and turbidity, the chlorophyll a exhibits moderate importance as compared to turbidity; therefore, from Table 7, a factor of 2 is assigned to it as it is indicated in Table 8. This procedure should be continued in row of chlorophyll a for all parameters given in the columns, and this should be repeated for all rows. In the diagonal of Table 8, a value of 1.00 can be found according to the meaning. The values in the triangle under the diagonal are the reciprocal values of the figures given above the diagonal.

The matrix obtained is shown in Table 8. This matrix is the basic matrix for the determination of the individual weights of the water chemistry parameters. During the preparation of the basic matrix, it is expedient to seek for the advice of experts if needed.

The following legends are used in the Tables 8 and 9: DO is dissolved oxygen; OS is oxygen saturation; Chla is chlorophyll a; TU is Turbidity; EC is conductivity.

Table 10 The weight indices (WI) of the water chemistry parameters

Water chemistry parameter	Weight index WI
Chlorophyll a	1.49
Turbidity	1.18
pH	3.16
Conductivity	2.33
Dissolved oxygen	8.29
Oxygen saturation	8.29
BOD_5	5.63
COD_{cr}	11.79
NH_4-N	4.14
NO_3-N	4.14
Total N	11.79
PO_4-P	18.88
Total P	18.88
Sum	100.00

The matrix obtained will be used for the following operations. The figures/matrix elements given in the columns of Table 8 should be summed up (Saaty 1980). This addition should be accomplished for every matrix elements of the water chemistry parameters given in the columns. As far as it can be seen in the bottom row of Table 8, the sum of the matrix elements of column chlorophyll a is 63.50. The sum of the matrix element of column turbidity is equal to 74.00, etc. For the normalization, the individual numerical figures/matrix elements of Table 8 are divided by the sum of the weights given in the row "sum." In the column of "Chlorophyll a," the matrix element figures are divided by 63.50.

In this way, a normalized matrix can be generated as shown in Table 9.

The next step is the determination of the average figures of the rows (C_i) given in the generated normalized matrix (Saaty 1980). The average of the all relative importance figures results in the actual importance. For example, for the determination of average importance figure of the pH (C_{pH}), the following step is taken (see Eq. (5)):

$$C_{\mathrm{pH}} = \frac{0.05+0.05+0.03+0.05+0.02+0.02+0.02+0.03+0.02+0.02+0.03+0.03+0.03}{13} = 0.03 \qquad (5)$$

The average figures of the rows of the normalized matrix (C_i) should be multiplied by 100, and in this way, a particular weight index (WI) for the water chemistry parameters can be obtained as it is shown in Table 10.

The weight indices represent the importance of water chemistry parameters. It is known that the pH influences several other parameters, e.g., the solubility of the components. However, in spite of this, regarding the actual situation not the parameter, pH has the highest weight index. On the basis of the COD, it can be mentioned that the water may contain organic molecules, hydrocarbons with lower, and higher carbon numbers or even toxic chemicals.

The weight indices of the method devised are in harmony with the statements of the literature (Jensen and Andersen 1992) according to which the organic load has a high impact onto the water quality of the Lake Balaton.

In consideration of the quality of the water, it can be concluded that the phosphorus content and COD and the total N are the most important parameters in Table 10, representing the highest importance weights (18.88, 11.79, 11.79), in accordance of the conclusions of the research of Verhoven et al. (1996). These are followed by the importance weights for the dissolved oxygen, oxygen saturation, etc.

The dissolved oxygen content and the oxygen saturation are in harmony with each other. During the study, the weight indices do not change; therefore, it is sufficient to determine these figures only one time.

According to Fig. 1, the confirmation of the weight indices calculated will be accomplished (step 8) whether those are in accordance of the professional judgment.

Evaluation of the water chemistry parameters

The evaluation of the water chemistry parameters is carried out for the case of the water of Lake Balaton taken at Balatonfüred as indicated in Fig. 6. The deviation of the measured water chemistry parameter from the legal limit value is plotted in function of the importance weights of the water

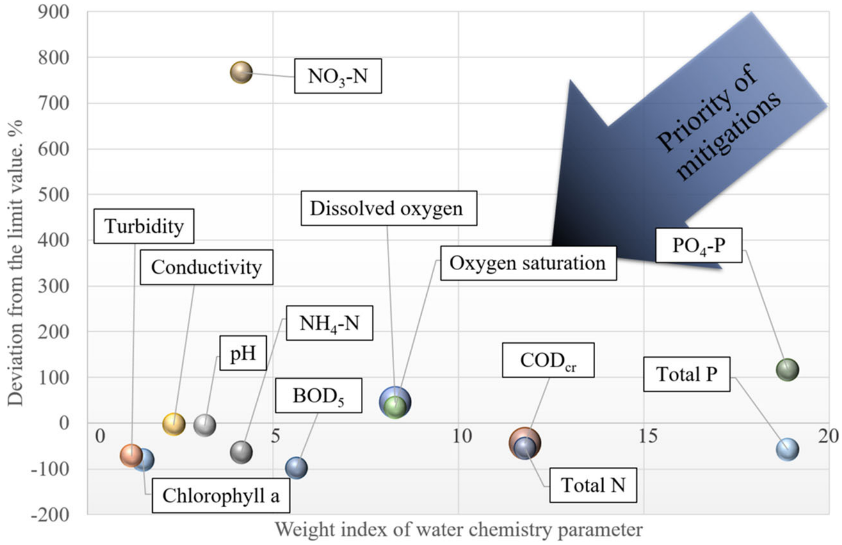


Fig. 6 Deviation of the water chemistry parameters from the limit values in function of the importance weight

Table 11 Evaluation categories for the quality classes

Category	Mean value	AEI interval
Bad	7.69	11.54 > AEI
Weak	15.38	11.54 ≤ AEI < 19.23
Proper	23.08	19.23 ≤ AEI < 26.93
Good	30.77	26.93 ≤ AEI < 34.62
Excellent	38.46	34.62 ≤ AEI

chemistry parameters as given in Fig. 6. The deviation from the legal limit value is calculated according to Eq. (6).

$$Q_{Di} = \frac{-(C_{Lvi} - C_{Mi})}{C_{Lvi}} \times 100 \qquad (6)$$

where Q_{Di} is the deviation of water chemistry parameter i from the legal limit value; C_{Lvi} is limit value of water chemistry parameter i; and C_{Mi} is the measured value of water chemistry parameter i.

On the basis of the parametric level analysis of the data of case study, it can be seen that the phosphate exhibiting high weight index can be found in the water in higher concentration than the limit value.

It is to be noted that the phosphorous is below the limit value and has a relatively high weight index. The dissolved oxygen content and the oxygen saturation are slightly higher than the limit values. The basic goal of the parametric level analysis is to identify the parameters of key importance which are critical in the case of the water body. In Fig. 6, these key parameters can be found above the axis x on the right hand side of the figure.

It is recommended to elaborate mitigation actions and measures for environmental parameters which can be characterized with a weight index higher than 10 and/or the deviation from the limit value is higher than 100 %. If several weight indices exceed the value of 10, then the measures should be implemented according to the priority sequence (Fig. 6) in order to improve the water quality.

In the final outcome of the assessment of the water chemistry parameters, the final qualification can be obtained according to the calculation given as follows. On the basis of the quality classes obtained from Table 6 and the weight indices of the water chemistry parameters (Table 10) with using the Eq. (7), the aquatic environment index (AEI) can be calculated.

$$\mathrm{AEI} = \frac{\sum_{i=1}^{n} QC_i \times \mathrm{WI}_i}{n} \qquad (7)$$

where AEI is aquatic environment index; QC_i is quality class for the water chemistry parameter i (on the basis of Table 6); WI_i is weight index for water chemistry parameter i (on the basis of Table 10); and n is number of the water chemistry parameters (number of parameters used in the study).

Discussions

Evaluation categories have been set up by mathematical interpretation of different cases for the quality categories with using Eq. (7). Assuming different quality classes and substituting these values into Eq. (7), the average AEI values of the different classes and the range of the different classes can be established. The determination of the

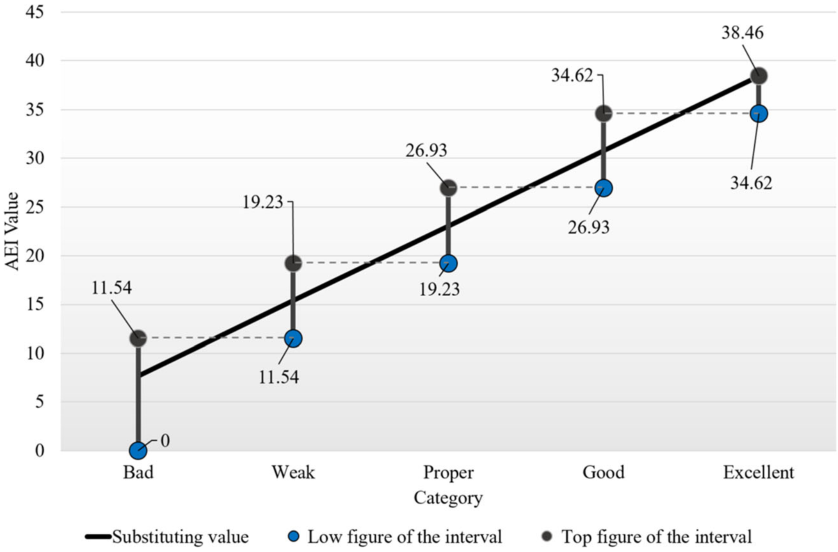


Fig. 7 Evaluation categories of the aquatic environment

Table 12 Determination of the aquatic environmental index

Parameter	Measured value (Balatonfüred)	Quality class, QC	Weight index, WI	$QC_i \times WI_i$
Chlorophyll a, μg/l	2.84	5	1.49	7.47
Turbidity, NTU	14.30	4	1.18	4.73
$pH_{alkaline}$	8.73	4	3.16	12.64
Conductivity, μSv/cm	773.90	3	2.33	6.98
Dissolved oxygen, mg/l	10.89	5	8.29	41.46
Oxygen saturation, %	106.91	5	8.29	41.46
BOD_5, mg/l	0.50	5	5.63	28.16
COD_{cr}, mg/l	16.58	5	11.79	58.95
NH_4-N, mg/l	0.02	5	4.14	20.72
NO_3-N, mg/l	0.52	1	4.14	4.14
Total N, mg/l	0.63	5	11.79	58.95
PO_4-P, mg/l	0.02	1	18.88	18.88
Total P, mg/l	0.05	5	18.88	94.38
AEI value				**30.69**

evaluation intervals given in Table 11 was carried out on the basis of the weighted figure of the quality classes. Water body of excellent quality means that all water chemistry parameters are in the excellent quality class. All water chemistry parameter classes were substituted into the Eq. (7), and the appropriate weight indices were considered for the calculation of AEI. If all water chemistry parameters have been ranked into quality class 1 (bad quality), then the index AEI will be equal to 7.69. In case of quality classes 2, the AEI = 15.38; in case of quality class 3, AEI = 23.08; in case of quality class 4, AEI = 30.77; and in case of quality class 5, AEI = 38.64.

The low and top limit values of the intervals were determined by the mathematical averaging of the neighboring AEI figures. For example, (7.69 + 15.38) / 2 = 11.54. In this way, the top figure of the bad interval is equal to 11.54. This logic can be followed for the determination of the low and top figures of the intervals as it can be seen in Fig. 7.

On the basis of the quality classes and weight indices, the aquatic environmental index (AEI) can be calculated by Eq. (7), as summarized in Table 12.

The AEI value calculated by Eq. (7) for the water of Lake Balaton at Balatonfüred is as follows:

$$\mathrm{AEI} = \frac{5 \times 1.49 + 4 \times 1.18 + 4 \times 3.16 + 3 \times 2.33 + 5 \times 8.29 + 5 \times 8.29 + 5 \times 5.63 + 5 \times 11.79 + 5 \times 4.14 + 1 \times 4.14 + 5 \times 11.79 + 2 \times 18.88 + 5 \times 18.88}{13}$$
$$= 30.69$$

Table 13 The evaluation table

AEI	Description
$34.62 \le \mathrm{AEI}$	The state of the water body is excellent. There is no anthropogenic impact and/or natural impact which influence the aquatic environment.
$26.93 \le \mathrm{AEI} < 34.62$	The state of the water body is good. The anthropogenic impacts are below the limit values and the natural impacts are negligible.
$19.23 \le \mathrm{AEI} < 26.93$	The water body is moderately polluted. The anthropogenic impacts can be observed on the water body and/or the natural impacts influence the water body.
$11.54 \le \mathrm{AEI} < 19.23$	The water body is polluted. The anthropogenic impacts are obvious. The utilization possibilities are limited. The mitigation technologies and measures are requested, and the financial implications are significant.
$11.54 > \mathrm{AEI}$	The water body is heavily polluted. It can be considered as wastewater not as natural water. The treatment of the water body requests heavy financial expenditures, and the future quality of the water body is doubtful.

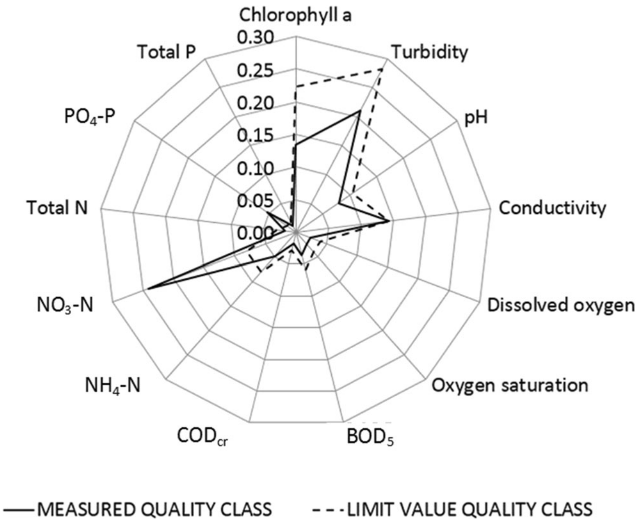


Fig. 8 Pollution profile of the water of Lake Balaton at Balatonfüred in comparison with the limit value

The results can be evaluated with using Table 13. The value of AEI determined is to be ranked into the appropriate category. A brief explanation is given in Table 13 on the environmental status of the given case. It should be noted that on the basis of the present study, there is no possibility to make exact distinction between the anthropogenic and natural impacts on waters; however, in light of additional measurements and studies, the pollution source and nature of the pollution can be identified.

The change of the aquatic environmental index in the function of the quality categories can be seen in Fig. 7.

On the basis of the calculations, the aquatic environmental index of the water of Lake Balaton is equal to 30.69. According to Table 13, it means that the state of the water body is good. The anthropogenic impacts are below the limit values and the natural impacts are negligible. This is in full harmony with the conclusions of Water Management Plan II (2015).

In Fig. 8, the deviation of the measured water chemistry parameters from the limit value can be seen. Figure 8 indicates the pollution profile of the water body, where the scale indicates the inverse figure of the product of multiplication of the quality class of water chemistry parameter *i* and the weight index of the water chemistry parameter *i*.

More precise calculations can be done if the exact distances are considered among the peak points or if the areas under the polygons are considered which could provide information on compliance with the legal regulations.

It should be mentioned that different techniques and scenarios as given in the literature (Donia and Bahgat 2016) can be used to assess the main water chemistry parameters like BOD, COD, DO, the nutrient compounds, etc. in order to optimize the future mitigation actions to be accomplished.

Conclusions

It can be concluded that the method devised and described in the paper is suitable for describing the status of water bodies from water chemistry's point of view. The present paper dealt only with water chemistry parameters to define the quality of the water; however, the method is suitable to incorporate additional water body qualifying parameter sets, e.g., biological, hydromorphological, other specific contaminations, etc. as well. The algorithm devised is flexible and it can be extended with additional evaluation criteria if needed.

The advantage of the method is that it provides a particular importance weighting among the environmental parameters.

The water quality of Lake Balaton was evaluated on the basis of the water sample taken at Balatonfüred. The water chemistry parameters measured and the method resulted in qualification "good" for the water of Lake Balaton.

However, in our case, in order to be in the position to submit a recommendation on the actions to improve the quality of water of Lake Balaton, additional water qualifications have to be carried out. The method devised can easily be combined with other techniques as well to elaborate future actions and mitigation plans to improve the water quality. The results of the measurements already carried out on the water of the Lake Balaton at several points around the lake will be dealt with in a separate paper.

The algorithm devised easily can be used for environmental data processing and visual interpretation also can be incorporated into the program. This supports the work of specialists on making reports on water bodies according to the Water Framework Directive. The future objective is to extend the model for processing biological, hydromorphological, etc. features of the waters in order to provide a full comprehensive picture on the quality of the aquatic environment.

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