Avrupa Bilim ve Teknoloji Dergisi
Sayı 19, S. 836-842, Ağustos 2020

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
No. 19, pp. 836-842, August 2020

Research Article

Application of CCME WQI to assess drinking water quality under Turkish national legislations: Lake Aygır

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(First received 8 July 2020 and in final form 29 August 2020)

(DOI: 10.31590/ejosat.766166)

ATIF/REFERENCE: Çavuş, A. & Şen, F. (2020). Application of CCME WQI to assess drinking water quality under Turkish national legislations: Lake Aygır. *European Journal of Science and Technology*, (19), 836-842.

Abstract

In this study, different guidelines have been determined in many legislations for the evaluation of drinking water of Lake Aygır in Bitlis. In monitoring water quality, CWQI was chosen as a model. In this model, the guideline values in Turkish national legislation, which determine the quality of drinking water, are used. Selected legislations: "Regulation on Water for Human Consumption", "Water-Water for Human Consumption", "Regulation on Surface Water Quality Management", "Regulation on Quality and Purification of Drinking Water Supply Water" and their index values are 86.21, 86.23, 88.88 and 84.71 respectively. $CWQI_{ASQ-Y}$ has been determined as 72.48 and $CWQI_{ASQ-M}$ has been determined as 81.75 within the "Regulation on the Amendment of the Surface Water Quality Regulation". Lake Aygır waters are classified in medium quality according to $CWQI_{ASQ-Y}$ and in good quality according to all other guidelines.

Keywords: CCME WQI, Turkish national legislations, water quality.

1. Introduction

Water for human consumption is used for drinking, cooking, food preparing, and cleaning purposes. Creeks, rivers, etc. streams; lake, dam, etc. stagnant waters and spring waters can be used in its original form or after purification (TSE 2005).

Water management is the development, distribution, and use of water resources in a planned way. Water resources management is to use water more planned and economically, to identify and prevent problems threatening water resources, and to protect water and water-related ecosystems. (Şen, 2017). One of the quick and easy ways to manage water is to use water quality indices.

The water quality index (WQI) is a way to summarize in simple terms reporting a large number of water quality data for water resources management (Akkaraboyina and Raju, 2012).

The Canadian Water Quality Index was developed by the Canadian Department of Environment. It is a widely used model (Bharti and Katyal, 2011). In this model, evaluation is made according to the frequency of sampling of WQI variables, frequency of unsuccessful variables, and deviations from target values given in the standards. The model does not define any water quality parameters or time concepts as the parameters will vary from location to location and depend on environmental conditions. It is subjective to determine the guideline values that are suitable for the use of water without expert opinion and validation. In calculating this index, at least four parameters, and at least four measurements of these parameters are sufficient (CCME, 2001).

Until now, different parameters and different formulas have been selected to obtain water quality indices. Oxygen saturation (OS), biological oxygen demand (BOD_5), turbidity, total solids, nitrate, phosphate, pH, temperature, fecal coliform (FC), pesticide and toxic compounds for NSF-WQI (Brown et al. 1972; McClelland 1974), dissolved oxygen (DO), electrical conductivity (EC) and turbidity for WQI_{min} (Pesce and Wunderlin, 2000), Secchi disk depth, chlorophyll-a and total phosphorus for the Carlson Trophic Status Index (Carlson and Simpson, 1996), DO, turbidity, total phosphorus, fecal coliform, specific conductivity for a WQI by Said et al. (2004) must be measured.

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In CWQI and other water quality index comparisons, the results of water quality indices created by using the parameters selected according to the basin with the help of experts are more suitable. The advantage of CWQI is that it concludes by using all the parameters measured under the desired legislation. There is no need for mandatory parameters or expert opinion. It gives superficial information about the water supply quality.

In this study, the water quality results of Lake Aygır in the study of Çavuş (2018) were used for the implementation of CWQI. The protection and better management of this water resource, which is used for different purposes, add a special value to the study.

2. Material ve Methods

2.1. Study area

Lake Aygır (38 ° 50 ′ 14 ″ N, 42 ° 49 ′ 20 ″ E) is located on the south of Mount Suphan in Adilcevaz, Bitlis (Figure 1, Golden Software 2010, Google Earth, 2018). There is a village on its shore. The water of Lake Aygır has a freshwater character and is used for drinking, irrigation, fishing, cage aquaculture, and recreational activities. No industrial establishment was found in the region. (Güllü and Güzel, 2006; Elp et al., 2014; Çavuş and Şen, 2018; Çavuş and Şen, 2020).

Figure 1.The Lake Aygır.

2.2. Dataset of Analysis

Analysis data were taken from a thesis study supported by Van Yuzuncu Yil University Scientific Research Projects Directorate. In the thesis, it's reported that five sampling stations were established. Sampling was performed thirteen times monthly (May 2015-May 2016). Water samples were stored in 1000 ml sample bottles and put in the cooler box. There were 51 water quality parameters measured in-situ and in the laboratory (Çavuş, 2018).

2.3. Calculation of CWQI

The Canadian water quality index formula was given below (CCME, 2001).

$$\mathrm{CWQI} = 100 - \left[\frac{\sqrt{\mathrm{F1}^2+\mathrm{F2}^2+\mathrm{F3}^2}}{1.732}\right] \quad \text{Equation 1}$$

The formulas of the unknown in Equation (1) are given in Equation (2, 3, 8).

CWQI: Canada Water Quality Index

F1: represents the percentage of the parameter, ie scope, that exceed its limit in the manual.

F2: represents the percentage of individual tests in each parameter that exceed its limit in the manual, ie frequency.

F3: represents the measure (deviation) of the failed test that exceeded its limit in the manual, the multiplicity. This is calculated in three stages. First, the deviation is calculated (Equation 4, 5, 6). Second, the normalized sum (nse) of deviations is calculated (Equation 7). Then a formula is applied for nse to change between 1 and 100 (Equation 8).

$$\mathrm{F1} = 100 * \frac{\text{Number of failed variables}}{\text{Total number of variables}} \quad \text{Equation 2}$$

$$\mathrm{F2} = 100 * \frac{\text{Number of failed tests}}{\text{Total number of tests}} \quad \text{Equation 3}$$

$$\mathrm{excursion}_i = \left[\frac{\text{Failed test value}_i}{\text{Objective}_i}\right] - 1 \quad \text{Equation 4}$$

$$\mathrm{excursion}_i = \left[\frac{\text{Objective}_i}{\text{Failed test value}_i}\right] - 1 \quad \text{Equation 5}$$

$$\mathrm{excursion}_i = \text{Failed test value}_{i\ i} \quad \text{Equation 6}$$

$$\mathrm{nse} = 100 * \frac{\sum_{i=1}^{n} \mathrm{excursion}_i}{\text{\# of tests}} \quad \text{Equation 7}$$

$$F3 = \left[\frac{nse}{0.01 * (nse+1)}\right]$$ Equation 8

2.4. Classification of CWQI

The calculated Canadian water quality index values are classified into five categories (CCME, 2001, Table 1).

Table 1. Categories of Canadian water quality index values.

Categories	Values
Excellent water	(95-100)
Good quality water	(80-94)
Fair quality water	(65-79)
Marginal quality water	(45-64)
Poor quality water	(0-44)

2.5. Selection of quality criteria

There are some points to consider when choosing legislation. Turkey Presidency of Administrative Affairs, General Directorate of Law and Legislation has been decided to publish official newspapers on the internet. The legislation published in official newspapers is based on. A legislation searched from the website www.resmigazete.gov.tr appears as published. The provisions that have been amended or removed later in the mentioned legislation are not available at this address. To find the mentioned provisions, the number of legislation (eg 29327) or name was searched from the address https://www.mevzuat.gov.tr. Removed, amended articles, chapters, or abolished regulations have been determined. Thus, updates on water quality standards could be followed. As a result of the researches, it was deemed appropriate to select the regulations in Table 2.

Tablo 2. General information about national legislations included drinking water purpose.

Legislation	Legislation number	Year	Institution	Abbreviations
Water-Water for Human Consumption	TS 266	2005	Industry and Trade Ministry	TS 266
Regulation on Water for Human Consumption	25730	2005	Ministry of Health	WHC
Regulation on Surface Water Quality Management	28483	2012	Ministry of Forestry and Water Management	SQM
Regulation on the Amendment of the Surface Water Quality Regulation	29797	2016	Ministry of Forestry and Water Management	ASQ
Regulation on Quality and Purification of Drinking Water Supply Water	30823	2019	Ministry of Agriculture and Forestry	QPDS

Water quality index was calculated on raw water quality results. There are several national regulations to which CWQI can be applied for drinking water. These are "Regulation on Water for Human Consumption", "Water-Water for Human Consumption", "Regulation on Surface Water Quality Management", "Regulation on Quality and Purification of Drinking Water Supply Water" and “Regulation on the Amendment of the Surface Water Quality Regulation”. Detailed information about the legislations was given in Table 2.

TS 266 “Waters-Waters for human consumption” was published in 2005 by the Turkish Standards Institute of Turkish Ministry of Industry and Trade (TSE). This standard is used to determine the quality of the water used for drinking water. Information about when, and by which institution, the other regulations were published was given in Table 2.

ASQ-Y is the annual average environmental quality standards that will compare the arithmetic average of the 1-year monitoring results of the parameters included in the “Regulation on the amendment to the surface water quality regulation”. In exceptional cases (accidents, natural disasters, etc.), the individual monitoring data of any parameter is compared to the maximum permissible environmental quality standard (ASQ-M). As a result of the evaluation, if the monitoring data are lower than both MAK standard and YO standard values, environmental quality standard values of the receiving environment are provided.

Class I values, based on the Quality Criteria of the Continental Surface Water Resources in SQM (2012) and ASQ (2016), were chosen as CCME target values. Class II was selected as limit value.

It is stated that the environmental quality standards specified in SQM (2012) should be met for the parameters not included in QPDS (2019) (Anonim, 2017).

The “Regulation on the Quality of Surface Water to be obtained or Planted to be Drinking Water” published in the Official Gazette dated 29/6/2012 and numbered 28338 has been repealed (Anonymous, 2019). The quality standards and classification given in the “Regulation on Quality and Treatment of Drinking Water Supply Water” published in the Official Gazette dated 06.07.2019 and numbered 30823 was examined instead.

A1 class in QPDS (2019) has been selected as the guide values of $CWQI_{QPDS}$. Because A1 class refers to water that becomes potable after simple physical treatment and disinfection. At the same time, it is similar to the guide features selected in other regulations. The reason why A2 and A3 classes are not chosen as guidelines is the need for chemical treatment (A2) and advanced treatment (A3).

Article 7 (Classification of Continental Surface Surface Water) and Article 8 (Determination of Water Quality Class) in the third part (Quality Classification of Water Environments) of the "Regulation on Water Pollution Control" have been abolished. For details on classification, the "Surface Water Quality Management Regulation" No. 28483 has been referenced (Anonymous, 2004). CCME WQI will not be applied to Anonymous (2004) due to the removal of the regulation articles.

Fourteen of the parameters measured in Lake Aygır are common in Turkish national legislations. Apart from the common ones, the number of the parameters measured in the Lake Aygır are 11 in the QPDS, 9 in the SQM, and 7 in the WHC, ASQ, and TS 266. Water quality parameters for legislations are presented in Figure 2. TS 266 and WHC parameters are exactly the same. The difference between these two regulations stems from the guidelines.

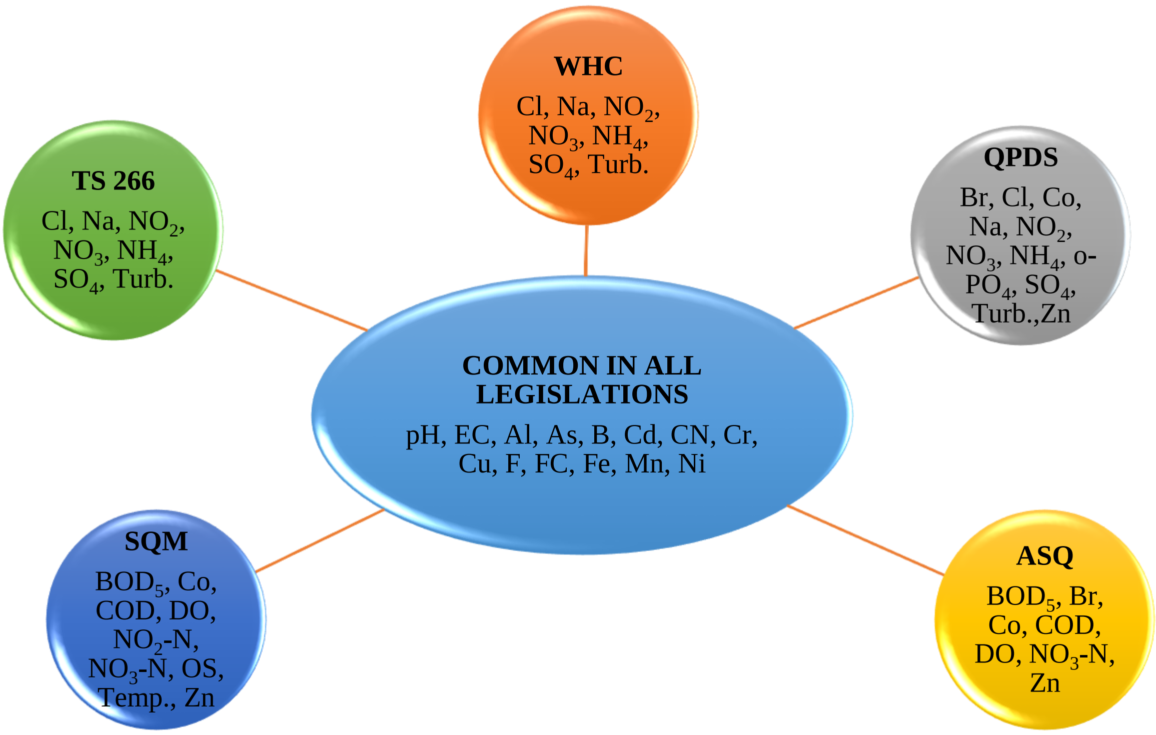

Figure 2. In the legislation water quality parameters, measured in Lake Aygır.

3. Results and Discussion

In the evaluation of Lake Aygır, 25 of the parameters in QPDS were used. The failed parameters of QPDS (2019) were turbidity, arsenic, fluoride, cadmium, and orthophosphate. $CWQI_{QPDS}$ value, obtained by adapting CCME WQI to QPDS standards, determined as 88.44. The value was classified in good quality waters according to the classification of CCME WQI. The frequency of individual tests of each parameter failing to meet the limits established with the QPDS legislation, totaled 18 occurrences. Most non-compliance value showed turbidity (%61) (Table 3, Table 4, Table 7).

Table 3. Number of failed parameters in regulations

	QPDS	WHC	TS 266	ASQ-M	ASQ-Y	SQM
Al					14 (4%)	
As	2 (11%)	2 (7%)	2 (12%)			
Br				63 (35 %)	93 (26%)	
Cd	3 (17%)	3 (11%)	3 (18%)	19 (11%)	89 (25%)	3 (4%)
CN				2 (1%)	40 (11%)	
Cu				77 (43%)	100 (28%)	
DO				17 (9%)	17 (4.7%)	17 (24%)
F	1 (6%)	1 (4%)	1 (6%)	1 (1%)	1 (0.3%)	1 (1%)
FC		10 (37%)	10 (59%)			
NO_2-N						1(1 %)
Turbidity	11 (61%)	11 (41%)	1 (6%)			
o-PO_4	1 (6 %)					
OS						33 (46%)
pH						16 (23%)

In the evaluation of Lake Aygır, 21 of the parameters in WHC were used. The failed parameters of WHC (2005) were turbidity, arsenic, fluoride, cadmium, and fecal coliform (FC). $CWQI_{WHC}$ value, obtained by adapting CCME WQI to WHC standards, determined as 86.21. The value was classified in good quality waters according to the classification of CCME WQI. The frequency of individual tests of each parameter failing to meet the limits established with the QPDS legislation, totaled 27 occurrences. Most non-compliance value showed turbidity (%41) (Table 3, Table 4, Table 7).

Table 4. F1 values of the legislations

Legislation	Number of failed variables	Total number of variables	F1
QPDS	5	25	20.00
WHC	5	21	23.81
TS 266	5	21	23.81
ASQ-M	6	21	28.57
ASQ-Y	7	21	33.33
SQM	6	23	26.09

In the evaluation of Lake Aygır, 21 of the parameters in TS 266 were used. The failed parameters of TS 266 (2005) were turbidity, arsenic, fluoride, cadmium, and fecal coliform. $CWQI_{TS\ 266}$ value, obtained by adapting CCME WQI to TS 266 standards, determined as 86.23. The value was classified in good quality waters according to the classification of CCME WQI. The frequency of individual tests of each parameter failing to meet the limits established with the QPDS legislation, totaled 17 occurrences. Most non-compliance value showed fecal coliform (%59) (Table 3, Table 4, Table 7).

Table 5. F2 values of the legislations

Legislation	Number of failed tests	Total number of tests	F2
QPDS	18	3141	0.57
WHC	27	2757	0.98
TS 266	17	2757	0.62
ASQ-M	179	2623	6.82
ASQ-Y	354	2623	13.50
SQM	71	2894	2.45

In the evaluation of Lake Aygır, 21 of the parameters in ASQ were used. The failed parameters of ASQ-M were dissolved oxygen, fluoride, cadmium, copper, bromide, and cyanide. $CWQI_{ASQ\text{-}M}$ value, obtained by adapting CCME WQI to ASQ standards, determined as 81.75. The value was classified in good quality waters according to the classification of CCME WQI. The frequency of individual tests of each parameter failing to meet the limits established with the QPDS legislation, totaled 179 occurrences. Most non-compliance value showed Cu (%43) (Table 3, Table 4, Table 7).

In the evaluation of Lake Aygır, 21 of the parameters in ASQ were used. The failed parameters of ASQ-Y were dissolved oxygen, fluoride, cadmium, aluminum, copper, bromide, and cyanide. $CWQI_{ASQ\text{-}Y}$ value, obtained by adapting CCME WQI to ASQ standards, determined as 72.48. The value was classified in fair quality waters according to the classification of CCME WQI. The frequency of individual tests of each parameter failing to meet the limits established with the QPDS legislation, totaled 354 occurrences. Most non-compliance value showed Cu (%28) (Table 3, Table 4, Table 7).

In the evaluation of Lake Aygır, 23 of the parameters in SQM were used. The failed parameters of SQM (2012) were pH, oxygen saturation (OS), dissolved oxygen (DO), nitrite nitrogen, fluoride, and cadmium. $CWQI_{SQM}$ value, obtained by adapting CCME WQI to SQM standards, determined as 84.71 . The value was classified in good quality waters according to the classification of CCME WQI. The frequency of individual tests of each parameter failing to meet the limits established with the QPDS legislation, totaled 71 occurrences. Most non-compliance value showed OS (%46) (Table 3, Table 4, Table 7).

Table 6. F3 values of the legislations

Legislation	∑excursion	∑excursion/# of tests	F3
QPDS	22.33	0.01	0.70
WHC	45.77	0.02	1.63
TS 266	29.71	0.01	1.07
ASQ-M	346.05	0.13	11.66
ASQ-Y	1194.64	0.46	31.29
SQM	115.12	0.04	3.83

The CWQI results were close to each other. The reason that the results are not exactly the same was caused by the variability of the regulation parameters and/or guide values (Figure 2). CWQI categorization ranged from “fair” to “good,” most legislations were “good” (80%), followed by “fair” (20%) water quality.

There are studies in the literature where water quality is determined in various surface waters by applying CWQI model. A water quality assessment was made in 2010 on a part of the Tigris River (Baghdad, Iraq) with CWQI. CWQI results ranged from 37 to 42 (poor). It's reported that serious action should be taken (Al-Janabi et al., 2012). The water quality of 15 rivers was determined by applying CWQI model in New Brunswick (Canada) (El-Jabi et al. 2014). In the Damodar River (India), CWQI was applied to the data set obtained for one year for eight sampling points (Haldar et al. 2016). The Canadian model guides local authorities to improve water quality from tropical reservoirs (Braga et al. 2015; Perbiche-Neves et al. 2017), rivers (Villa-Achupallas et al. 2018) and floodplain lakes (Fantin-Cruz et al. 2016) (Sutadian et al. 2016).

Table 7. CWQI values of the legislations

Legislation	F1	F2	F3	CWQI
QPDS	20.00	0.57	0.70	88.44
WHC	23.81	0.98	1.63	86.21
TS 266	23.81	0.62	1.07	86.23
ASQ-M	28.57	6.82	11.66	81.75
ASQ-Y	33.33	13.50	31.29	72.48
SQM	26.09	2.45	3.83	84.71

4. Conclusions and Recommendations

The main purpose of Turkish directives is to protect public health and the environment by defining guideline values for water quality indicators. Indices are an objective way to evaluate aquatic ecosystems; Its results provide important information on decision making by competent authorities to better manage water ecosystems. Lake Aygir data set were applied to the Canadian water quality index (CWQI), and the legislation of the Republic of Turkey. Thus, drinking water quality were determined. As a result, the average $CWQI_{drinking}$ and were calculated as 83.30 ± 5.74. Calculated water quality index value was classified in good quality waters. Due to the low population of Lake Aygır village and no industrial establishment around it, the CWQI might have been at a "good" quality. The lake may have missed an "excellent" quality due to the presence of a village on the shore, cage fishing and its geological structure.

In five legislation failed parameters were pH, OS, DO, NO_2-N, Al, As, Cd, CN, Cu, Br, F, turbidity, and FC. Lake Aygır is supplied to Aydınlar Town as drinking water (Çavuş, 2018; Çavuş and Şen, 2020). We do not have information about the filtration of Lake Aygır waters reaching the Aydınlar town. Therefore, we cannot advise on the filtering of these parameters.

In the lake soft computing models can be used instead of the traditional procedure because they reduce time, cost, effort and sometimes computational errors. One of the intelligent models is fuzzy logic approach that solves complex problems dealing with uncertainty and uncertainty data. Adaptive neuro-fuzzy inference system (ANFIS) can be used to predict, informate, simulate to systems which has little experience with data behavior like Lake Aygır. In modeling of Lake Aygır water quality index different hybrid intelligence models based on ANFIS integrated with fuzzy c-means data clustering, grid partition and subtractive clustering models can be used (Yaseen et al., 2018; Sonmez et al., 2018). Therefore, use of hybrid ANFIS can be suitable to follow up the water quality index in further researches.

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