Environ Monit Assess (2010) 167:115–124
DOI 10.1007/s10661-009-1035-1

Utilization of the water quality index method as a classification tool

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Received: 16 January 2009 / Accepted: 3 June 2009 / Published online: 20 June 2009

Abstract The study comprised modification of the Canadian Council of Ministers of the Environment (CCME) Water Quality Index (CCMEWQI) to obtain a tool in classification of surface waters according to quality defined by the European Legislation—75/440/EEC. Three categories were proposed, and the category ranges of CCMEWQI have been modified depending on the objective chosen. The application of the CCMEWQI with modified categorization scheme was demonstrated to assess overall water quality by integrating observed water quality determinants in the Kucuk Menderes Basin, Turkey. In this scope, the samples analyzed for pH, total dissolved solids (TDS), chlorides (Cl), nitrate–nitrogen (NO_3–N), dissolved oxygen (DO), biochemical oxygen demand (BOD_5), sulfate (SO_4), and boron (B), variables taken monthly over 2 years from the five monitoring sites, were processed. Results revealed that the overall surface water mainly fell within the A2 water class. The CCMEWQI with modified categorization scheme is believed to assist water managers to integrate and interpret the picture of overall water quality based on the European legislation concerning the quality required of surface water intended for the abstraction of drinking water in the Member States (75/440/EEC).

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Keywords Kucuk Menderes Basin · Canadian Council of Ministers of the Environment (CCME) Water Quality Index · 75/440/EEC · Turkish Water Pollution Control Regulation

Introduction

Quality of water is defined in terms of its physical, chemical, and biological parameters. Ascertaining the quality is crucial before use for various purposes such as drinking; agricultural, recreational, and industrial uses; etc. (Sargaonkar and Deshpande 2003; Khan et al. 2003). Monitoring programs of aquatic systems play a significant role in water quality control since it is necessary to know the contamination degree so as not to fail in the attempt to regulate its impact (Almeida et al. 2007). However, the quality is difficult to evaluate from a large number of samples, each containing concentrations for many parameters (Almeida et al. 2007).

Traditional approaches comprise complex variable-by-variable and water body-by-water body statistical summaries, which are inadequate to integrate and interpret a picture of overall water quality to the public, managers, and policy makers, who require concise information about those water bodies. Water quality indices (WQI) have been developed with the aim of providing summary information on quality. It is a mechanism for presenting a cumulatively derived numerical expression defining a certain level of water quality (Bordalo et al. 2006). In other words, WQI summarizes large amounts of water quality data into simple terms (e.g., excellent, good, bad, etc.) for reporting to management and the public in a consistent manner.

The concept of WQI is based on the comparison of the water quality parameters with respective regulatory standards and gives a single value to the water quality of a source, which translates the list of constituents and their concentrations present in a sample (Khan et al. 2003; Abbasi 2002). The index method was initially proposed by Horton in 1965 (Horton 1965). Since then, the formulation and use of indices has been strongly advocated by agencies responsible for water supply and control of water pollution. For example, US National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), Oregon Water Quality Index (OWQI), and the Florida Stream Water Quality Index (FWQI) have been developed (Debels et al. 2005; Kannel et al. 2007; Abbasi 2002).

The CCMEWQI allows the index user to select the reference objectives that measured water quality is compared with. This is an advantage of the index being applied by the water agencies in different countries. In that case, based on the variables and objective chosen, modification of the categorization scheme might be required. In the study, CCMEWQI has been modified depending on the European Community Standard—75/440/EEC. The application of CCMEWQI with a new categorization scheme was demonstrated to classify overall water quality in the Kucuk Menderes River Basin, Turkey.

Table 1 Canadian water quality standards for different water uses (after Khan et al. 2003)

Water quality variables	Unit	Water uses		
		Drinking	Aquatic	Agriculture
Iron	mg/L	0.3	0.3	5
Manganese		0.05	0.1[BC]	0.2
Lead		0.01	0.001	0.2
Nickel		0.2[BC]	0.025	0.02
Zinc		5	0.03	5
Aluminum		0.2[BC]	0.005	5
Chromium		0.05	0.002	0.008
Copper		1	0.002	1
Phosphorous		0.1[a]	0.1[a]	n/a
Dissolved organic carbon		5[ON]	n/a	n/a
Arsenic		0.025	0.005	0.1
Selenium		0.01	0.001	0.02
Mercury		0.0001	0.0001	0.003
Barium		1	n/a	n/a
Hardness		500	n/a	n/a
Sulfate		500	n/a	1,000
Chloride		250	n/a	250
Floride		1.5	n/a	1
Dissolved oxygen		n/a	5[BC]	n/a
Specific conductance	μS/cm	700[BC]	n/a	n/a
Turbidity	JTU	1	n/a	n/a
pH	Maximum	8.5	9	n/a
	Minimum	6.5	6.5	n/a

All other criteria are from Canadian Environmental Quality Guidelines and Guidelines for Canadian Drinking Water Quality

n/a not applicable or not available, *BC* British Columbia Provincial Water Quality Guidelines, *ON* Ontario Provincial Water Quality Guidelines

[a]Recommended as maximum desirable concentration

Material and methods

Canadian Council of Ministers of the Environment Water Quality Index

In 1997, the CCMEWQI technical subcommittee formulated an index that could be used nationally. The application of the method requires water quality guidelines or objectives. Therefore, for each site and water use, different sets of parameters (also knows as variables) can be used depending upon the availability of data and regulatory standards. Most applications of the CCMEWQI to date have used national and other provincial standards presented in Table 1 (Khan et al. 2005).

The general steps involved in the determining CCMEWQI can be summarized as:

- Choosing variables
- Choosing guidelines
- Calculating index scores (Khan et al. 2004)

The index is based on a combination of three factors:

- F_1: the number of variables whose objectives are not met (scope)
- F_2: the frequency by which the objectives are not met (frequency)
- F_3: the amount by which the objectives are not met (amplitude)

The formulation of the WQI is as follows (CCME 2001): The measure for scope—F_1—represents the extent of water quality guideline noncompliance over the time period of interest:

$$F_1 = \left[\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right] * 100 \tag{1}$$

F_2—frequency—represents the percentage of individual tests that do not meet objectives ("failed tests"):

$$F_2 = \left[\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right] * 100 \tag{2}$$

The measure of amplitude—F_3—represents the amount by which failed test values do not meet their objectives. It is calculated in three steps:

(a) The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an "excursion" and is expressed as follows: When the test value must not exceed the objective:

$$\text{excursion}_i = \left[\frac{\text{Failed test value}}{\text{Objective}_j}\right] - 1 \tag{3}$$

Table 2 CCMEWQI categorization scheme (CCME 2001)

Categorization	Index values	Remark
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time
Good	80–94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Table 3 Characteristic of surface water intended for the abstraction drinking water (75/440/EEC)

Water quality variables	Unit	Water quality class		
		A1	A2	A3
Total suspended solids	mg/L	25	na	na
Nitrates		25	na	na
Fluorides		0.7–1	0.7–1.7	0.7–1.7
Dissolved iron		0.1	1	1
Manganese		0.05	0.1	1
Copper		0.02	0.05	1
Boron		1	1	1
Zinc		0.5	1	1
Arsenic		0.01	na	0.05
Cadmium		0.001	0.001	0.001
Mercury		0.0005	0.0005	0.0005
Sulfate		150	150	150
Chloride		200	200	200
Phosphate		0.4	0.7	0.7
Biochemical oxygen demand		<3	<5	<7
Ammonia		0.05	1	2
Nitrogen by Kjeldahl method except NO_3		1	2	3
Colorination	mg/L Pt scale	10	50	50
pH		6.5–8.5	5.5–9	5.5–9
Total coliforms	/100 ml	50	5,000	50,000
Temperature	°C	22	22	22
Conductivity (at 20°C)	μS/cm	1,000	1,000	1,000
Dissolved oxygen saturation rate	$\%O_2$	>70	>50	>30
Odor (dilution factor at 25°C)		3	10	20

na not applicable

For the cases in which the test value must not fall below the objective:

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

(b) The collective amount by which individual tests are out of compliance is calculated as:

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{\# of tests}} \quad (5)$$

nse is referred to as the normalized sum of excursions

(c) F_3 is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = \left[\frac{\text{nse}}{0.01\text{nse} + 0.01}\right] \quad (6)$$

The WQI is then calculated as:

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right] \quad (7)$$

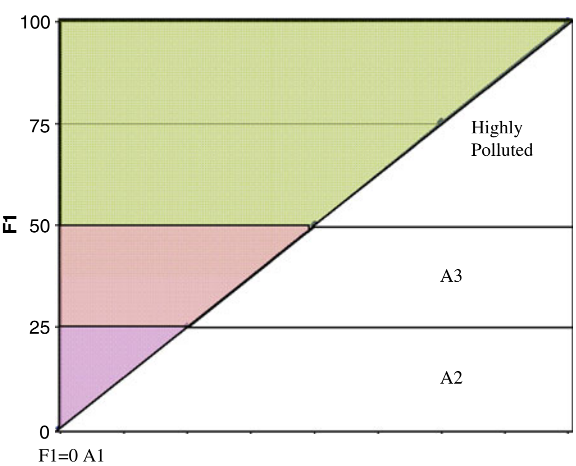

Fig. 1 Scope values (F_1%) assigned to A1, A2, and A3 categories

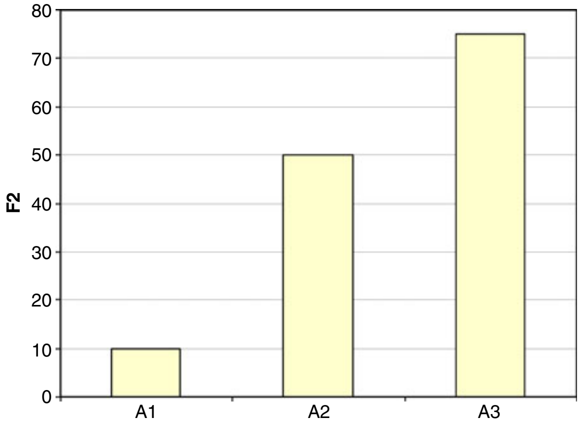

Fig. 2 Frequency values (F_2%) set for A1, A2, and A3 class waters

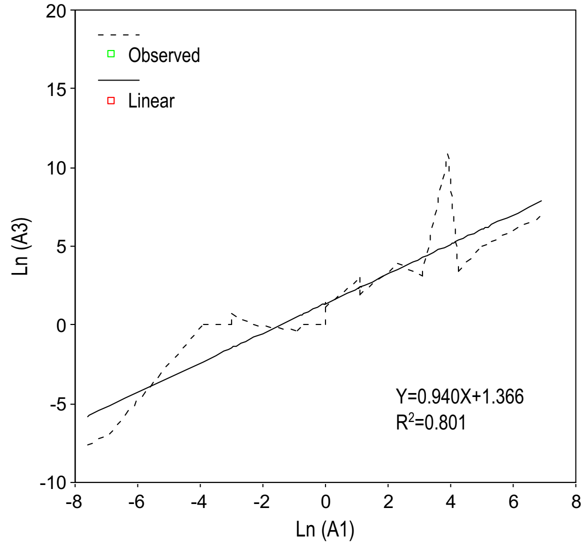

Fig. 4 A1 vs A3 threshold values

The result can be further simplified by assigning it to a descriptive category represented by a number between 1 and 100. Four categories have been suggested to categorize water in CCMEWQI. Index values and details on the quality of water in each category are given in Table 2. As was mentioned, application of the CCMEWQI based on different regulatory standards may require modification of these category ranges. If the CCMEWQI categorization scheme is modified by referencing European legislation concerning the quality required of surface water intended for the abstraction of drinking water in the Member States (75/440/EEC), it could be possible to classify inland water based on the European classification scheme and determine the degree to which the intended use is supported.

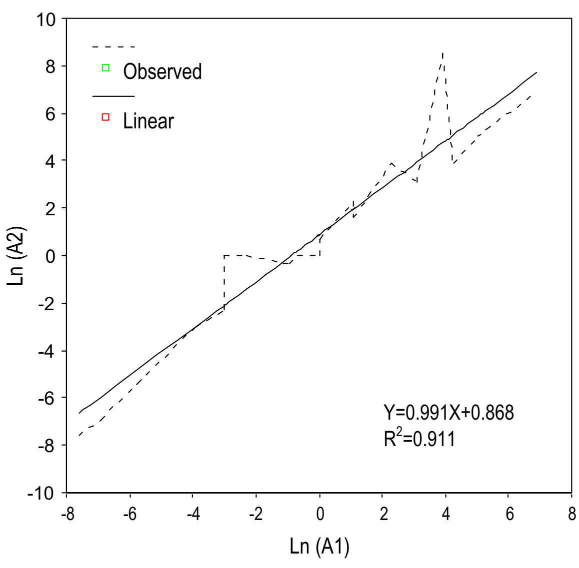

Fig. 3 A1 vs A2 threshold values

Modification of CCMEWQI index scheme

75/440/EEC classifies the water quality of inland waters into three categories, A1, A2, and A3,

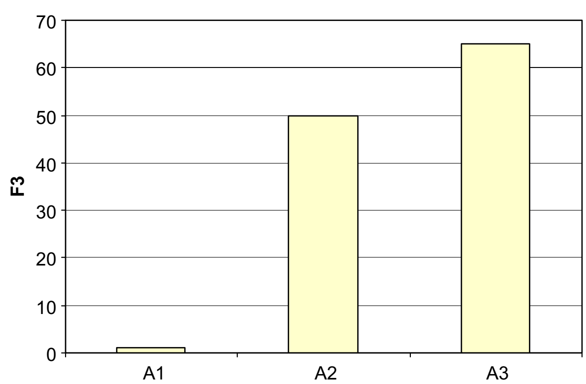

Fig. 5 Amplitude values (F_3%) assigned to A1, A2, and A3 class waters

Table 4 Components of modified CCMEWQI categorization scheme

Factors		Water quality class		
		A1	A2	A3
F_1		0	25	50
F_2		10	50	75
F_3	$\text{excursion}_i = \left[\frac{\text{Failed test value}}{\text{Objective}_j}\right] - 1$	0	1.0	2.0
	$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{\# of tests}}$	0	≈ 1.0	≈ 2.0
	$F_3 = \left[\frac{\text{nse}}{0.01\text{nse}+0.01}\right]$	0	≈ 50	≈ 65
$\text{WQI} = 100 - \left[\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right]$		≈ 95	≈ 55	≈ 35

which correspond to the appropriate standard methods of treatment.

Category A1: Simple physical treatment and disinfection, e.g., rapid filtration and disinfection

Category A2: Normal physical treatment, chemical treatment, and disinfection, e.g., prechlorination, coagulation, flocculation, decantation, filtration, disinfection (final chlorination)

Category A3: Intensive physical and chemical treatment, extended treatment, and disinfection, e.g., chlorination to break-point, coagulation, flocculation, decantation, filtration, adsorption (activated carbon), disinfection (ozone, final chlorination) (EC 1991)

The comprehensive list of variables having guide values in the 75/440/EEC is given in Table 3.

In the study to classify surface waters into one of these three categories using the CCMEWQI method, a new categorization scheme was proposed by taking characteristics of the A1, A2, and A3 water classes as reference. In this scope, A1 represented *high quality*, A2 *moderate quality*, and A3 *slightly polluted waters*.

According to 75/440/EEC, "the surface water shall be assumed to conform to the relevant parameters if samples of this water taken at regular intervals at the same sampling point and used in the abstraction of drinking water show that it complies with the parametric values for the water quality in question, in the case of

- Ninety percent of the samples for parameters conforming to those specified in the standard given in Table 3
- In the case of the 10% of the samples that do not comply
- The water does not deviate from the parametric values in question by more than 50%, except for temperature, pH, dissolved oxygen, and microbiological parameters
- There can be no resultant danger to public health
- Consecutive water samples taken at statistically suitable intervals do not deviate from the relevant parametric values (EC 1991).

In the proposed categorization scheme index, a score of "100" was assigned to A1 water class. On the other hand, relative changes of threshold values of A2 and A3 water classes (see Table 3) vs A1 were used to calculate new index score components (F_1, F_2, and F_3) representing A2 and

Table 5 Modified CCMEWQI categorization scheme based on European standard

Water quality class	Index scores
A1	95–100
A2	55–94
A3	35–54

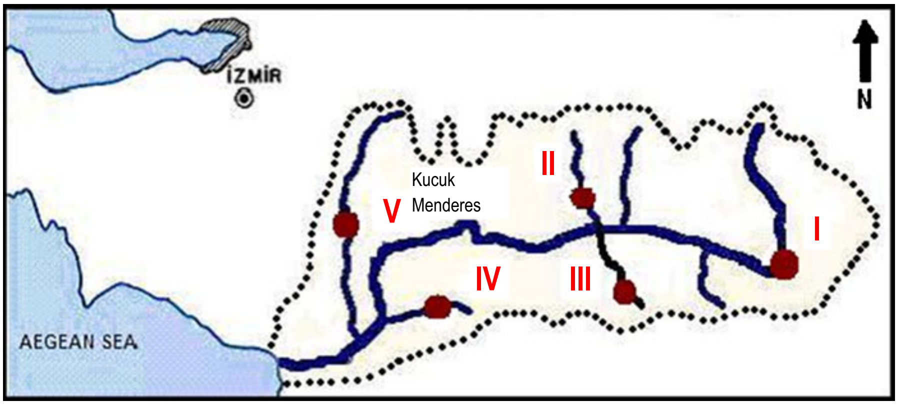

Fig. 6 Kucuk Menderes River Basin

A3 categories. These three factors determined the range of index scores representing each quality class (A1, A2, and A3).

As was regulated by the 75/440/EEC, if ever more than 50% of the variables exceed the limit set for A1 waters, this source is not proposed for drinking water supply. Accordingly, the percentage of the number of failed variables to total number of variables (F_1) was set to 0 for A1 and 50 for A3 waters. Furthermore, F_1 was proposed as 25% for the A2 class (see Fig. 1).

It was stated by 75/440/EEC that, unless more than 10% of the samples violate the limit value in data sets, this variable would not be accepted as in compliance with this limit. Similarly, in the study percentage of individual tests that do not meet objectives (frequency), F_2 was set to 10% for A1 waters. Additionally, this ratio was assumed as 50% for A2 and 75% for A3 waters (see Fig. 2).

The correlations between the threshold values of A1–A2 and A1–A3 categories were examined using regression analysis to determine F_3—amplitude values. Results revealed that there was strong positive linear correlation between log-transformed values of A1–A2 and A1–A3 classes (see Figs. 3 and 4). Regression equations are:

$$\text{Ln}\,(\text{A2}) = 0.991 * \text{Ln}\,(\text{A1}) + 0.868\left(r^2 = 91\%\, p < 0.01\right)$$

$$\text{Ln}\,(\text{A3}) = 0.940 * \text{Ln}\,(\text{A1}) + 1.366\left(r^2 = 80\%\, p < 0.01\right)$$

The average rate of the threshold values of A2 and A3 to A1 waters (in other words, the ratio of failed test value to objective value) were calculated as about two and three. Accordingly, excursions were 1.0 for A1 and 2.0 for A2 classes. Thus, F_3—amplitude—values representing A2 and A3

Table 6 The classification of inland waters according to quality-Turkish Water Pollution Control Regulation (Official Gazette, 2004)

Water quality variables	Unit	Class I	Class II	Class III
Total dissolved substances	mg/L	500	1,500	5,000
Nitrate nitrogen		5	10	20
Chloride		25	200	400

Table 7 Kucuk Menderes Basin Surface water quality classes

Water quality variables	Unit	Water quality monitoring stations				
		I	II	III	IV	V
pH		A3	A3	A3	A3	A3
Dissolved oxygen	mg/L	A3	A2	A2	A2	A3
Sulfate		A1	A1	A1	A1	A1
Nitrate–nitrogen		A1	A1	A1	A1	A2
Total dissolved substances		A2	A1	A1	A1	A2
Biochemical oxygen demand		A2	A1	A2	A2	A2
Chloride		A2	A2	A2	A2	A2
Boron		A1	A1	A1	A1	A1

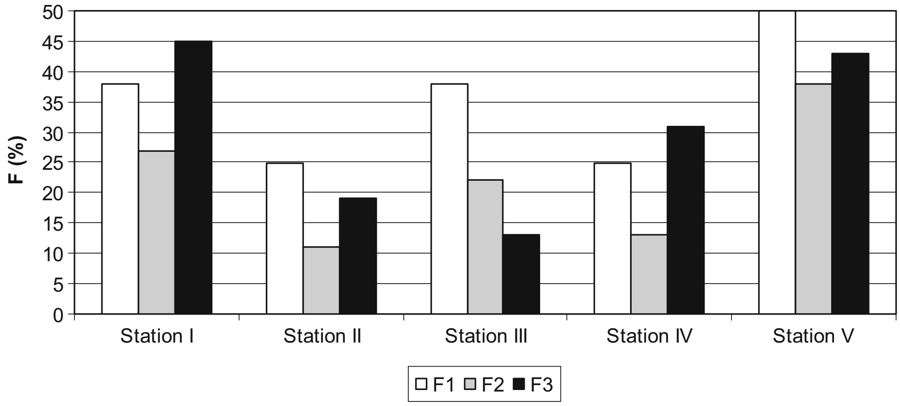

Fig. 7 Scope, frequency and amplitude values at monitoring stations in Kucuk Menderes Basin

waters were defined as 50% and 65% (see Fig. 5 and Table 4).

Three factors (F_1, F_2, and F_3) that were determined based on the calculations and assumptions for the threshold values representing three categories (A1, A2, and A3) are presented in Table 4. Proposed ranges of index scores assigning to each water quality class are given in Table 5.

Study area

In the study, the application of the CCMEWQI with modified categorization scheme was demonstrated to assess overall water quality by integrating observed water quality determinants in the Kucuk Menderes Basin, Turkey. The Kucuk Menderes Basin is located in Western Anatolia and covers almost 0.9% of the country with 6,907 km^2 drainage area. Seferihisar, Torbali, Selcuk, Tire, and Odemis, etc., are settlements in which 370,000 inhabitants live, as of 2000, in the basin (Fig. 6). The climate of the region is typically Mediterranean: hot and dry in summers and temperate and rainy in winters. The length of the Kucuk Menderes River is 107 km, and its main tributaries are Ulucay, Kocahavran, Camlı, Keles, and Aktas streams. The average discharge is 0.2 m^3/s in summer and 4 m^3/s in winter. The economy of the basin depends on agricultural production. Domestic and agricultural discharges are main pollution sources deteriorating water quality in the region (IPDMEF 2004; TURKSTAT 2002).

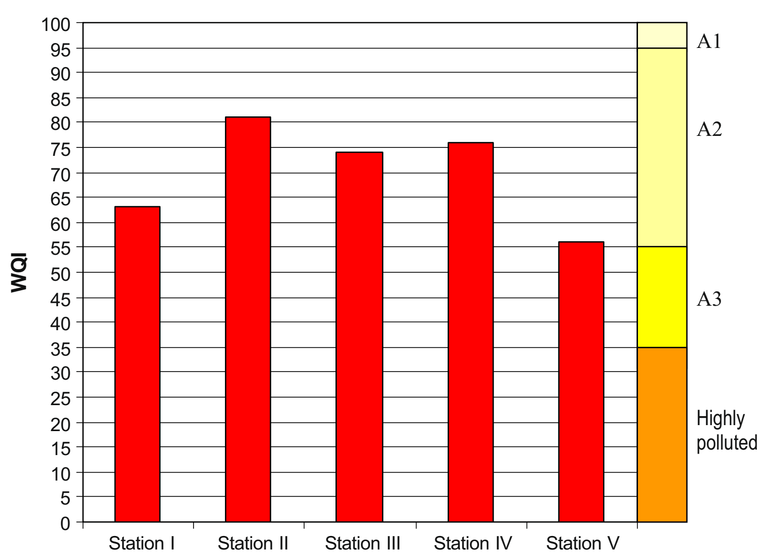

Fig. 8 Kucuk Menderes Basin surface water quality classes based on European classification scheme

In this study, the samples analyzed for pH, total dissolved solids (TDS), chloride (Cl), nitrate–nitrogen (NO_3–N), dissolved oxygen (DO), biochemical oxygen demand (BOD_5), sulfate (SO_4), and boron (B) parameters taken monthly over 2 years from the five monitoring sites were assessed. The main idea behind the selection of these variables was that they represent general water quality and do not incorporate specific water functions. Threshold values representing each class for these parameters are given in Table 3.

Results

Kucuk Menderes Basin surface water quality classes, which were determined by taking the 90th percentile of the each data set as characteristic value, are presented in Table 6. Since there is no threshold value differentiating each quality class for total dissolved solids (TDS), chlorides (Cl), and nitrate–nitrogen (NO_3–N) in 75/440/EEC, the Turkish Water Pollution Control Regulation (WPCR), which has a quite similar categorization scheme, was referenced for these variables. The main difference between the Turkish standard—Water Pollution Control Regulation—and 75/440/EEC is that water quality parameters, which exceed the threshold value set for third category, define class IV, but in the study, the fourth class was excluded, considering appropriateness of water quality for use. Threshold values for these variables are presented in Table 6.

Results revealed that the water quality generally fell within A1 and A2 classes based on the 90th percentiles (see Table 7). To integrate and interpret the picture of overall water quality of the Kucuk Menderes River instead of assessing variable-by-variable, the WQI at each site was calculated using the CCMEWQI method. Scope (F_1), frequency (F_2), and amplitude (F_3) for each data set are presented in Fig. 7. As is seen in the bar graph, almost 50% of the considered variables violated the threshold value set by the standard at site V. The frequency (F_2) was highest (almost 40%) at monitoring station V and lowest at stations II and IV (around 25%). The amount by which the objectives are not met (F_3) was highest at sites I and V (about 45%). According to the modified classification scheme, overall water quality was rated (see Fig. 8) and overall index scores showed that the surface water at all the stations mainly fell into the "A2" class.

Conclusion

The study investigated how index methods are effective in deriving the information from complex water quality data sets. In this scope, CCMEWQI was used to interpret data sets. On the other hand, the index scheme has been modified to meet requirements of classification of surface waters according to quality based on European legislation. In the proposed index classification scheme, inland waters were classified into three classes (A1, high quality; A2, moderate quality; and A3, slightly polluted waters), as is, in 75/440/EEC, "quality required of surface water intended for the abstraction of drinking water in the Member States." Characteristics of the objective and the opinions of the water experts were taken into account in this process and index scores "95–100" represented A1-, "55–94" A2-, and "35–54" A3-class waters.

The application of CCMEWQI with modified index categorization was demonstrated to assess overall water quality by integrating observed water quality determinants in Kucuk Menderes Basin, Turkey. The samples analyzed for pH, total dissolved solids (TDS), chlorides (Cl), nitrate–nitrogen (NO_3–N), dissolved oxygen (DO), biochemical oxygen demand (BOD_5), sulfate (SO_4), and boron (B) parameters taken monthly over 2 years from the five monitoring sites were processed. Results revealed that the overall surface water quality mainly fell into the "A2" class. This study showed that the CCMEWQI with modified categorization may assist water managers to integrate and interpret the picture of overall water quality based on the European legislation (75/440/EEC).

Acknowledgement The author expresses special thanks to State Hydraulic Works (DSI) for cooperation in providing data.

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