

Alhassan H. Ismail

Faculty of Power Engineering,
Department of Hydraulics and
Environmental Engineering,
University POLITEHNICA of
Bucharest, Bucharest, Romania
hassan19851988@yahoo.com

Diana Robescu

Faculty of Power Engineering,
Department of Hydraulics and
Environmental Engineering,
University POLITEHNICA of
Bucharest, Bucharest, Romania

Muntaser A. Hameed

Institute of Technology, Middle
Technical University,
Department of water resources
techniques, Baghdad, Iraq

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Application of CCME WQI in the Assessment of the Water Quality of Danube River, Romania

Abstract- An attempt has been made to assess the water quality of the Danube River using water quality index technique. In this study, the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) was selected to express the quality of water for drinking water abstraction and to provide information on the spatial and temporal variations of the river water quality. Water quality of 13 parameters has been considered in four sampling stations during 1-year period. The European Community (EC) standards for drinking water abstraction were used for CCME WQI calculation. The water quality variables included in the index are dissolved oxygen, biochemical oxygen demand, ammonium, nitrates, total phosphorus, water temperature, pH, total suspended solids, cadmium, copper, chromium, nickel and lead. The results revealed that the water quality was found fair in all sampling stations except one station, which was marginal. It was observed that the most important variables that affected the water quality were ammonium, total phosphorous, water temperature and total suspended solids. Moreover, no significant changes were observed for temporal variation in the Danube river water quality. The CCME WQI gave reasonable results and introduced representative outcomes of the raw data of the river.

Keywords- Water quality assessment, CCME-WQI, Danube river.

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1. Introduction

The conventional process of water quality assessment is to compare the detected value of a variable, in a water sample, with an existing desirable limit of that variable. Many variables are needed to be determined in order to assess the quality of water. The tabulation and interpretation processes of these variables may cause confusion, especially for non-specialist in the water field [1]. Besides, it does not always give a comprehensive vision and integrated concept on the water quality status [2,3]. Water quality indices (WQIs) have been widely used to overcome this matter. It can be defined as the transformation of the measured values of different water quality parameters into a dimensionless number (scale from 0 to 100) using different aggregation method [4]. The highest number in the scale represents better water quality and lowest value indicates poorest water quality [5].

Horton [6] has developed the first water quality index based on 10 parameters. Thereafter, various indices have been suggested by different institutions and authors. For example but not limited to, National Sanitation Foundation Water

Quality Index [7], Prati's Index [8], Walskie-Parker index [9], Bascaron WQI [10], Bhargava's Index [11], Second Dinius' Index [12], Smith index [13], Aquatic Toxicity Index [14], the modified Oregon Water Quality Index [15], the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) [16], the Overall Index of Pollution [17], Universal Water Quality Index [18]. Each of these indices describes the water quality for general or specific uses. A detailed description of the aforementioned indices can be found in Abbasi and Abbasi [19].

This paper aimed at applying the CCME WQI to assess the water quality of the Danube river for drinking water abstraction and to provide information on the spatial and temporal variations of the river water quality at Drobeta-Turnu Severin region. CCME WQI was selected due to its advantages such as a large number of variables can be included in the calculation steps of CCME-WQI, its flexibility of selection the water quality standards and comparatively tolerant in case of missing data [20].

2. Materials and Methods

I. Study area and water quality data

The Danube River is divided into three main parts: the upper Danube course (1060 km), the middle Danube course (725 km) and the lower Danube course (1075 km). The lower Danube course represents Romania's natural border with Serbia, Bulgaria, Ukraine and the Republic of Moldova [21]. The river flows through regions of distinct morphology. In the lower course, the river is flowing through Baziaş and Gura Văii passing the Iron Gate I (14 km upstream of Drobeta-Turnu Severin city). The Iron Gate I was constructed in 1971 and considered as the largest dam and reservoir system based on volume, area and hydropower potential among numerous impoundments on the Danube and the tributaries [22]. Drobeta-Turnu Severin is a city in Mehedinţi County, Romania, on the left bank of the Danube, below the Iron Gates. The city administers three villages: Gura Văii, Dudaşu Schelei, and Schela Cladovei (Figure 1).

This study covers almost 13 km of the Danube River starting at Gura Văii, 2 km downstream of Iron Gate I, and extends to Drobeta-Turnu Severin city. The importance of this region is emerged due to the lack of proper sewage collection and treatment facilities in the Drobeta-Turnu Severin city, in addition to the effluent discharges from industrial areas in the region. Two major groups of industries exist in the region: southwest industrial area (upstream of Drobeta-Turnu Severin city), and southeast industrial area (downstream of Drobeta-Turnu Severin city) [23,24]. In addition to the utilization of fertilizers and pesticides from agricultural areas (Serbian part) and discharged to the river through surface runoff [25].

In the present paper, data sets of 13 parameters obtained during 1 year in four sampling points (collected at monthly intervals) namely, Gura Văii (SS1), which is about 2 km downstream of Iron Gate I, Dudaşu Schelei (SS2), Schela Cladovei (SS3), Drobeta-Turnu Severin (SS4) were subjected to CCME WQI. The descriptive statistics summary of water quality data, abbreviations, units, analytical methods and the European Community (EC) standards [26] for surface water quality used for drinking water abstraction are shown in Table 1.

II. The CCME WQI

The CCME-WQI index was employed by various countries all over the world to assess water quality [27-29]. The main advantage of this index is that a large number of variables can be included in the calculation steps of CCME-WQI. Therefore, in

this study, all the 13 water quality parameters were considered. It has a very different approach among others in which it comprised three factors for calculating the final index as [30-32]:

$$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right] \quad (1)$$

Where F_1 (Factor 1) is known as the scope and, F_2 (Factor 2) is known as frequency and F_3 (Factor 3) is known as amplitude. F_1 (scope) is calculated as

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right) * 100 \quad (2)$$

The number of failed variables represents the percentage of variables, which exceed the allowable limit value at least once during the monitoring period, relative to the total number of measured variables. F_2 (frequency) is calculated as:

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of variables}} \right) * 100 \quad (3)$$

The number of failed tests represents the percentage of individual tests that exceed the allowable limit value, relative to the total number of tests conducted during the monitoring period. F_3 (amplitude) can be calculated in 3 steps:

1. The calculation of the excursion

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

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

Excursion represents the number of times that the value of the variable exceeds the allowable limit value (objective). Eq. (4) is used if the value of a variable must not be greater than the allowable limit value such as BOD. Whereas, Eq. (5) is used if the value of a variable must not be less than the allowable limit value such as DO.

2. Evaluation of normalized sum of excursions (nse)

$$nse = \left(\frac{\sum_{i=1}^n excursion_i}{\text{Total number of tests}} \right) \quad (6)$$

(nse) is the ratio of the sum of excursions obtained for individual tests dividing by the total number of tests (both meeting and not meeting the objective values).

3. The last step is the calculation of F_3

$$F_3 = \left(\frac{nse}{0.01 nse + 0.01} \right) - 1 \quad (7)$$

The calculation of CCME WQI value in each station has been determined by Eq. (1) in order to produce a value between 0 and 100. Then, water quality is ranked in the following categories [16]:

- Excellent: (CCME WQI values 95–100)
- Good: (CCME WQI values 80–94)
- Fair: (CCME WQI values 60–79)
- Marginal: (CCME WQI values 45–59)
- Poor: (CCME WQI values 0–44).

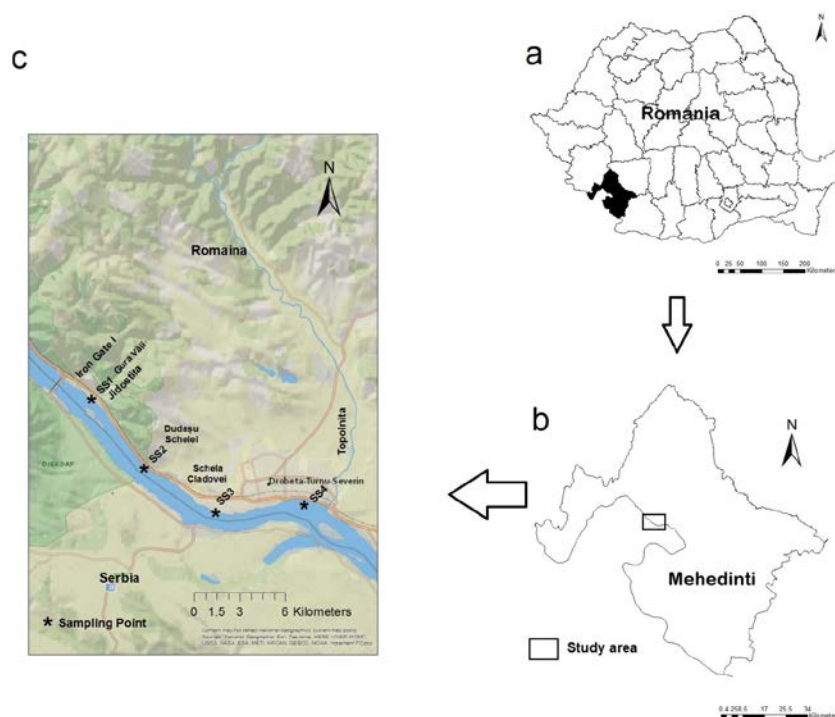


Figure 1: Map of the study area: a) Romanian Counties, b) Mehedinți County and c) Sampling Locations

Table 1: Water quality parameters, abbreviations, units, analytical method, EC standards and descriptive statistical summary of Danube River water quality data in four sampling stations during 1 year

Parameters	Abbreviations	Units	Instrument/techniques used	Min.	Max.	Mean	Std. Dev. ^a	EC standards ^b (Guide Level)
Dissolved Oxygen	DO	mg/L	Winkler azide method	5.61	12.69	9.12	2.09	>70%
Biochemical oxygen demand	BOD	mg/L	Winkler azide method	1.15	2.37	1.66	0.30	<3
Ammonium	NH ₄	mg/L	Spectrophotometric	0.087	0.522	0.19	0.07	0.05
Nitrate nitrogen	NO ₃	mg/L	Spectrophotometric	0.195	3.614	1.98	0.88	25
Total phosphorous	TP	mg/L	Spectrophotometric	0.132	1.44	0.43	0.27	0.1 ^c
Water Temperature	WT	°C	Mercury thermometer	4	27	15.72	7.27	22
pH	pH	-	pH-meter	7.1	7.7	7.43	0.15	6.5-8.5
Total suspended solids	TSS	mg/L	Gravimetric	21	34	26.44	2.93	25
Cadmium	Cd	μg/L	FAAS ^e	0.11	0.44	0.28	0.07	1
Copper	Cu	μg/L	FAAS ^e	1.5	4	2.16	0.71	20
Chromium	Cr	μg/L	FAAS ^e	1.4	3.5	1.97	0.53	50 ^d
Nickel	Ni	μg/L	FAAS ^e	1.1	1.8	1.43	0.19	50 ^c
Lead	Pb	μg/L	FAAS ^e	0.7	1.9	1.37	0.34	50 ^d

^aStd. Dev. – Standard Deviation, ^bdirective 76/464/EEC, ^cNational Administration of Romanian Waters, ^dmaximum allowable concentration. ^eFAAS - Flame atomic absorption spectrophotometer

3. Results and Discussion

The CCME WQI has been applied in order to interpret the water quality data in an easy and understandable way. The European Community (EC) standards for drinking water abstraction were used for CCME WQI calculation and presented in Table 1 [26]. EC standards proposed guidelines for surface water used as raw water for

drinking water based on three types: simple physical treatment and disinfection (A1), normal full physical and chemical treatment with disinfection (A2) and intensive physical and chemical treatment with disinfection (A3). The results of CCME WQI are shown in Table 2. Water quality standards values were presented as Guide Level (GL) value and Maximum

Allowable Concentration (MAC) value for 38 parameters. In this study, guide level values were considered for all variables except for Cr and Pb. In addition, total phosphorus and Ni were not included in EC standards and therefore, water quality standards from National Administration of Romanian Waters were used. In CCME WQI, all the variables were taken into account for the evaluation process. The water quality classification scheme for sampling stations was found fair in SS1, SS2 and SS4, whereas marginal in SS2. The most important variables that affect the water quality were NH₄, TP, WT and TSS.

It was observed that CCME-WQI has a totally different approach and distinct characteristics among other conventional indices. CCME-WQI has the ability to take into account all the water quality variables, in addition to its flexibility of selection the water quality standards and comparatively tolerant in case of missing data [20]. Moreover, it can be applied to assess the water quality for different uses and it does not utilize sub-index to transform the measurement of water quality into a unit less number. It comprised three factors for the evaluation process (scope, frequency, and amplitude). However, this index is not free of flaws such as considering all the water, quality variables have the same degree of importance and it can be applied only when there are available guidelines on the water quality parameters.

It can be concluded that the CCME-WQI has provided realistic results in comparison to the raw data of the Danube River. The results of CCME-WQI were fair in three stations (SS1, SS3 and SS4) and marginal in one station (SS2) (Figure 2). Fair category indicates that “the water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels”. Marginal category indicates that “the water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels” [16]. Generally, no significant changes were observed for temporal variation in the Danube river water quality.

Table 2: The calculated F factors along with WQI and categorization values of CCME-WQI index

St.	F1	F2	F3	CCME-WQI	Categorization
SS1	30.7	26.0	39.4	67.5	Fair
SS2	38.5	26.9	40.1	64.3	Marginal
SS3	30.7	23.7	44.7	65.8	Fair
SS4	30.7	24.3	41.3	67.1	Fair

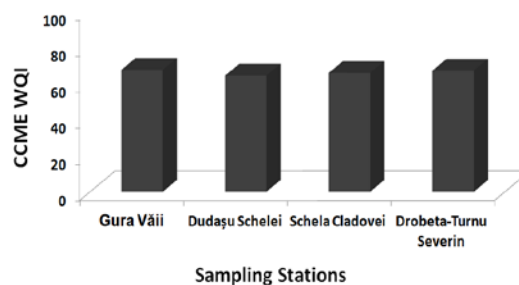


Figure 2: WQI values of CCME WQI in four sampling stations of the Danube River

4. Conclusion

This study comprised the applications of CCME-WQI to assess the physico-chemical water quality in the Danube River at Drobeta-Turnu Severin. The quality of water in the study area in four sampling stations ranged from marginal to fair. The most important variables that affect adversely the water quality were NH₄, TP, WT and TSS.

CCME-WQI uses a formula and does not include sub-indices for the implementation process. It comprised three factors for the evaluation process (scope, frequency, and amplitude). Moreover, all the water quality variables have been used in the calculation of CCME-WQI. It can be concluded that the CCME-WQI gave reasonable results in comparison to raw data of the river water. Therefore, CCME-WQI can be applied to assess the water quality in Danube River.

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