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Assessing the quality of bottled water brands using a new water quality index

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Abstract: The aim of the paper is to present a newly derived water quality index, specifically developed for assessing the quality of bottled water. Several requirements have been set by the European Union through legislation which all the member states are obliged to fulfil for the bottled waters available in their markets. So, the question arises how good these waters are, if the values of the various parameters shown on the labels are close to reality, and how the consumer can easily and quickly evaluate bottled water brands. A total of 79 different bottled water brands available in the Greek market were evaluated and compared using a specially designed bottled water quality index (BWQI). The index combines one microbiological and six physicochemical parameters. The assessment is based on both laboratory analysis results and values on bottle labels. The index calculator was installed at a specially designed webpage which is easily accessible via personal computers or smart phones. According to the results obtained, it is concluded that the majority of the bottled water samples examined were of excellent or very good quality, a small number was characterised as of good quality, and very few samples failed to attain the good quality status. The new water quality index proved to be a quick, sensitive and powerful tool to assess and compare the quality of bottled waters.

Key words: Bottled waters, water quality, laboratory tests, bottled water quality index (BWQI), multiplicative model

1. INTRODUCTION

Water intended for human consumption should be of high quality so that public health is protected (Tsakiris and Tsakiris, 2012). Water quality is recognized as the most important issue, not only related to consumers and their requirements, but also to the protection of the water resources and the environment (Benedini and Tsakiris, 2013).

The assessment of water quality is a difficult task due to the many parameters involved in its characterization. This difficulty was recognized and led to proposals for adopting simplified approaches, such as the water quality indices. A water quality index is a unique score which combines information based on a number of important water quality parameters.

The first modern water quality index was set by Horton (1965). Several water quality indices have been developed and used by researchers and institutions for rating water of various origins (e.g., Brown et al., 1970; Bhargava, 1983; CCME, 2001; Boyacioglu, 2007; Cude, 2001; Dunnette, 1980; Liou et al., 2004). The application of water quality indices in evaluating water bodies has a main advantage, which is the presentation of water quality state into a single digit score (Alexakis et al., 2016; Nuanchan, 2017). Moreover, many computer–automated tools and mathematical formulations have been developed in order to generate and introduce water quality indices (Sarkar and Abbasi, 2006; Swammee and Tyagi, 2000, 2007).

In the case of bottled water quality, no significant work has been done in developing water quality indices. This is most probably due to the fact that bottled water is generally considered as water of high quality (Toma et al., 2013). Toma et al. (2013) applied a water quality index in evaluating water quality in several bottled water brands of Iraq. Recently, a new index, suitable for the assessment of bottled water quality was developed (Tsakiris, 2016a, b). In this study, this index is used to assess the various brands of bottled water which are available in the Greek market.

2. THE BOTTLED WATER QUALITY INDEX

The Bottled Water Quality Index (BWQI) is a two-stage index. The first stage is an ON/OFF process testing the bottled water sample on fulfilling two requirements: (a) absence of population of the bacteria *Escherichia coli*; and (b) pH values lying between 6.5 and 9.5. If these two requirements are fulfilled, the evaluation procedure continues from the first stage to the second stage, which is based on a multiplicative model using five sub-indices with their corresponding exponents (Tsakiris, 2016a, b). The five sub-indices represent the following five physicochemical parameters: nitrate (NO_3^-), nitrite (NO_2^-), chloride (Cl^-), sulphate (SO_4^{2-}) and specific electrical conductivity (SPC). This multiplicative process is presented by Eq. (1):

$$\boldsymbol{BWQI} = \prod_{\boldsymbol{i=1}}^{\boldsymbol{N}} \boldsymbol{SI}^{\lambda_i} \tag{1}$$

In this equation, the exponents λ_i are the sensitivity coefficients and represent the sensitivity of each sub-index (SI) in the final index, while N represents the total number of sub-indices which take part in this multiplicative model. The determination of sensitivity coefficients is presented by Tsakiris (2016a, b). It is important to note that due to the multiplicative character of the index, the BWQI is very sensitive to each of the selected parameters. Further, in order to increase the impact of each sub-index on the final index, each coefficient of sensitivity is increased by 20 percent. Therefore, the coefficients of sensitivity for the multiplicative model of BWQI are $\lambda_1=\lambda_2=0.30$, $\lambda_3=\lambda_4=0.20$, $\lambda_5=0.20$ (Tsakiris, 2016a, b).

3. QUALITY PARAMETERS AND SUB-INDICES

The most critical issue in the development of the BWQI is obviously the selection of the parameters and the transformation process of the absolute values of the quality parameters into sub-indices.

As in the development of any water quality index, it is not possible to avoid the subjectivity when selecting the parameters of the proposed index. To decide which parameters to include and their severity of impact, several experts were consulted together with a thorough bibliographic analysis on the subject.

In regard to the transformation of the absolute values of the parameters to standardised values in the same scale 0-1, the membership function method, used in the fuzzy sets, was adopted. According to this method, the absolute values covering a range within the allowable boundaries are transformed by the membership function into values between 0 and 1. Triangular or trapezoidal types of membership functions are used for the parameters of *E.coli*, pH, nitrates, nitrites, chloride, sulphates and electrical conductivity (20 ºC), respectively. Graphically these membership functions are given by Tsakiris (2016a, b). It should be mentioned that the maximum absolute allowable values of the selected parameters are adopted by the values proposed in the European directive 98/83/EU. It is easily observed that if the absolute value is out of the permissible interval, the standardised value becomes zero. Due to the ON/OFF process (first stage) or the multiplicative model (second stage), if only one sub-index is zero, then the final BWQI becomes also zero.

In order to facilitate the easy and quick calculation of BWQI, an online application is built. The user is asked to fill a specially developed form including all the necessary water quality parameters in absolute values (concentration of *E. coli*, pH, nitrates, nitrites, chloride, sulphates and specific electrical conductivity). The final BWQI is calculated automatically after the submission of the inserted values.

The basic assumptions for the development of the BWQI are:

a) The bottled water is consumed by different people irrespectively of their age, gender, health status etc. It is also assumed that it is consumed continuously for long time. Based on these assumptions the proposed index has to be relatively general and fulfil the requirements of potable water (EC directives, WHO standards etc). These legislative documents were used for determining the boundaries of values above which the water is not appropriate for human consumption. Based on these thoughts the maximum allowable concentrations for the selected parameters of the BWQI are given in Table 1.

Table 1. Maximum allowable concentrations of BWQI parameters

Parameter	Unit	Allowable concentrations
Escherichia Coli	Number/250 mL	0
Nitrate (NO_3^-)	mg/L	0-50
Nitrite (NO_2^-)	mg/L	0-5
Chloride (Cl^-)	mg/L	0-250
Sulphate (SO_4^{2-})	mg/L	0-250
pH	pH scale	6.5-9.5
Electrical Conductivity (20°C)	μS/cm	0-2500

b) The bottled water is generally of good or excellent quality and there is no need to test it towards indicators which represent severe pollutants (e.g., test on BOD). However, for security reasons one microbiological parameter (concentration of bacteria *E. coli*) was included in the first stage process of the BWQI. The same applies to pH for which the bottled water has to fulfil the criteria $6.5 \leq pH \leq 9.5$.

c) The selected parameters involved in the multiplicative model belong to three categories with respect to their severity. It is assumed that the nitrates and nitrites belong to the first severity class (3). In the second class of severity (2) are chloride and sulphates and in the third class of severity (1) several salts (e.g., Ca^{++}, Na^+, K^+, etc.) represented by the electrical conductivity. It is also assumed that the first (highest) severity class has a triple impact on the final index in comparison to the third (lowest) severity class. Also, the second (medium) severity class has a double impact on the final index in comparison to the third (lowest) severity class. Finally, it is assumed that the sub-indices of the same severity class have the same coefficient of sensitivity.

4. ASSESSMENT OF BOTTLED WATER BRANDS USING THE BWQI

Using the Bottled Water Index, 79 brands of bottled water available in the Greek market have been assessed based on their labels. In general, most of the brands performed successfully with only 6 (that is 8%) being characterized as unacceptable according to the BWQI rating. Thirty seven brands (47%) reached scores above 0.85 and were characterized as excellent. Nine achieved scores between 0.70 and 0.85 and were assessed as good. Finally, 27 brands (34%) were not assessed due to missing information.

The assessment and rating of the various brands based on the laboratory tests showed slightly different results. The tests were performed in the Laboratory of Reclamation Works and Water Resources Management of the National Technical University of Athens through a number of Diploma theses (Tzima, 2012; Paloglou, 2012; Tsakiris, 2016a, b). From the 57 samples tested, 43 brands (75%) were rated as excellent (score above 0.85), 6 (11%) as good (scores between 0.70 and 0.85) and 8 (14%) were characterized as unacceptable according to the BWQI assumptions. The brands with their scores set in descending rating order appear in Table 2. The brands which failed in attaining successful scores appear with zero score in Table 2.

5. CONCLUDING REMARKS

In this paper, several brands of bottled water available in the Greek market have been assessed using the Bottled Water Quality index (BWQI). The BWQI consists of two stages. The first is a ON/OFF process for testing each bottled water sample against the *E. coli* concentration and the permissible range of pH. The second stage is a multiplicative model, which includes three types of the most representative quality parameters for bottled water assessment. According to the results obtained (using the information on the labels of the bottles and from laboratory tests), it is concluded that the majority of the bottled water samples examined are of excellent quality, a small number is of good quality, and very few failed to attain the good quality status. It can also be concluded that the new bottled water quality index proved to be a quick, sensitive and powerful tool to assess and compare the quality of bottled waters.

Table 2. The bottled water brand ratings based on laboratory tests and the BWQI

Brand code number	BWQI rating	Brand code number	BWQI rating
32	0.978	26	0.914
56	0.975	51	0.914
22	0.962	40	0.911
20	0.958	38	0.908
25	0.955	30	0.905
10	0.954	14	0.898
21	0.954	8	0.882
9	0.948	11	0.879
43	0.945	24	0.878
28	0.941	31	0.869
48	0.936	45	0.865
7	0.934	29	0.860
1	0.934	37	0.860
4	0.933	39	0.853
35	0.933	2	0.845
34	0.933	36	0.834
42	0.933	33	0.825
6	0.932	54	0.825
41	0.931	16	0.822
18	0.931	5	0.809
13	0.931	46	0.000
27	0.925	47	0.000
44	0.924	49	0.000
17	0.924	50	0.000
3	0.923	52	0.000
12	0.921	53	0.000
15	0.921	55	0.000
19	0.918	57	0.000
23	0.918		

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