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RESEARCH ARTICLE

Bottled water quality ranking via the multiple-criteria decision-making process: a case study of two-stage fuzzy AHP and TOPSIS

Ramin Nabizadeh[1] · Samira Yousefzadeh[2,3] · Kamyar Yaghmaeian[1] · Mahmood Alimohammadi[1] · Zahra Mokhtari[1]

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Abstract

Access to healthy drinking water is vital to human health and development. Bottled water consumption has been on the rise in recent years. As several chemical and bacteriological parameters affect bottled water quality, it is difficult to choose the highest-quality bottled water. Numerous studies have proposed the use of multiple-criteria decision-making (MCDM) methods to overcome this problem. Herein, the two-stage fuzzy analytic hierarchy process (FAHP) and technique for order preference by similarity to ideal solution (TOPSIS) method were adopted to rank different brands of bottled water. The FAHP approach allows working at the intervals of judgment rather than absolute values. TOPSIS is a technique for ordering performance based on its similarity to the ideal solution. An expert panel selected and classified the criteria and sub-criteria. A pairwise comparison questionnaire was then developed, and the weights of the criteria and sub-criteria were assigned by water quality experts. The data on the quality of different brands of water were collected from the Iranian bottled water database. The final data analysis and weight determination of each parameter were performed in Excel and R software Programs. Finally, the CC_i (value of closeness coefficient) and rank of 71 bottled water brands were calculated, and the best brand was introduced. Among the selected criteria, carcinogenic chemical compounds with the weight of 0.368 were the most important compound in ranking bottled water brands, followed by bacteriologic, pathogenic chemical compounds, chemical compounds important in terms of toxicity, nutritious chemical compounds with a low toxicity level, chemical compounds related to esthetic effects, and chemical compounds without health effects, respectively.

Keywords Bottled water · Fuzzy AHP · TOPSIS · MCDM · Water quality

Introduction

A challenge currently faced by developing countries is the lack of access to healthy drinking water (Abuzerr et al. 2019; Cobbina et al. 2015). Based on the World Health Organization's (WHO) report, about 663 million people worldwide do not have access to healthy drinking water (WHO 2017). The increased population growth, a lack of healthy drinking water, and the public opinion about good taste, health, and appropriate quality have increased bottled water consumption. This rise has been considered in the past three decades, with the highest consumption being reported in developing countries of Asia and South Africa (Hu et al. 2011). The bottled water sale rate was $198.50 billion in 2017, a value which is estimated to reach $307.2 billion by 2024 (Doria 2006). Therefore, access to healthy drinking water is vital to human health and development (Fisher et al. 2015).

Natural processes (erosion) and anthropogenic activities (electroplating, metal smelting, and chemical industries) are the main sources of pollutant entrance into the water. Although a few heavy metals are essential to human health, their excess amount can have negative effects such as anemia, renal dysfunction, cancer, and brain damage (Chowdhury

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✉ Zahra Mokhtari
zaaahra.mokhtari@gmail.com

1 Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Science, Tehran, Iran

2 Department of Environmental Health Engineering, School of Public Health, Semnan University of Medical Sciences, Semnan, Iran

3 Students' Scientific Research Center (SSRC), Tehran University of Medical Sciences, Tehran, Iran

et al. 2016; Gharibi et al. 2012; Qu et al. 2020; Qu et al. 2021a, b; Rezaee et al. 2015; Zhang et al. 2021). The existence of numerous parameters affecting water quality complicates bottled water quality assessment and ranking and decision-making about the purchase of the best and highest-quality brand. Therefore, there is a dire need for precise and logical techniques for accurate and scientific decision-making. To this end, studies have proposed various methods for choosing the best option and making the decision, among which MCDM methods have received considerable attention owing to their numerous advantages (Kou et al. 2014; Mulliner et al. 2016).

MCDM methods are adopted to solve decision-making problems and planning in the face of multiple criteria (Muruganantham and Gandhi 2020). These methods are popular and extensively utilized to find the best solution or option in different branches of science, such as engineering (Sakthivel et al. 2016; Shen et al. 2010; Shyur and Shih 2006; Yazdani-Chamzini et al. 2014; Yousefzadeh et al. 2020) and environmental sciences (Beskese et al. 2015; Meshram et al. 2019; Pires et al. 2011; Rezaian and Jozi 2012; Rikhtegar et al. 2014). A frequently used MCDM approach is the AHP method. According to the literature, from 1994 to 2014, the hybrid fuzzy MCDM with 19.89% was ranked the first among other approaches. AHP (15.82%), FAHP (8.53%), and TOPSIS (7.4%) methods were the most frequently used methods in 1081 papers. This method has gained momentum owing to its relative simplicity compared to MCDM methods, easier understanding, and not using complex mathematical calculations (Javanbarg et al. 2012; Torfi et al. 2010). Despite its popularity, the AHP method has always been criticized for its inability to face ambiguous and imprecise decision-making problems (Naderzadeh et al. 2017). Therefore, when decision-makers face a complex and ambiguous problem and express their opinions relatively and uncertainly, the standard AHP can no longer be suitable. Since the usual AHP cannot correctly reflect human thinking and due to the uncertainty and imprecision of pairwise comparisons, the fuzzy AHP or FAHP is employed in these cases (Archibald and Marshall 2018; Naghadehi et al. 2009; Serrano-Cinca and Gutiérrez-Nieto 2013; Singh et al. 2019).

The TOPSIS technique is another decision-making model employed in numerous decision-making problems by managers and planners. This technique is one of the best and most precise multiple-criteria decision-making methods, in which appropriate choices are those with a minimum distance from the positive ideal solution, i.e., the best case possible, and with a maximum distance from the negative ideal solution, i.e., the worst case possible. This technique is designed without including the type of indicators (in terms of having a positive or negative effect on the decision-making objective) in the model but considering the weight and degree of importance of each indicator (Kim et al. 1997; Shih et al. 2007; Zyoud and Fuchs-Hanusch 2017, 2019). Nowadays, the simultaneous use of these two techniques (FAHP-TOPSIS) has found extensive application for making important decisions (Ertuğrul and Karakaşoğlu 2009; Mandic et al. 2014; Paksoy et al. 2012; Seçme et al. 2009; Wang et al. 2009).

Accordingly, to overcome the problems associated with decision-making, herein, a hybrid FAHP-TOPSIS method was used as a systematic, popular, and frequently used method to solve multiple-criteria decision-making problems by using the fuzzy set theory (Mikhailov and Tsvetinov 2004; Yousefzadeh et al. 2020; Zyoud et al. 2016a, b).

Therefore, the main purpose of the present study is to create a comprehensive model for bottled water ranking in Iran. Also, this study aims to present results that can be simply used by senior managers to survey the performance of the factory producing bottled drinking water considering the quality of drinking water and treatment methods as well as establishing appropriate modification methods to meet the drinking water criteria.

So, to achieve these purposes, a comprehensive database of physical, chemical, and bacteriological parameters of Iranian bottled water was employed and five main steps were followed to weight the criteria and sub-criteria: 1, investigating the parameters' health and esthetic effects; 2, classifying the parameters into groups of criteria and sub-criteria based on their effects; 3, forming a panel of experts to weigh the parameters; 4, using the FAHP method to determine the fuzzy weight of each element and finally; 5, implementation of the TOPSIS method to rank the choices (71 brands).

Method

Sample size

The sample included the physicochemical and bacteriological parameters of 71 bottled water brands in Iran (Latifi et al. 2015). The data on the quality of water from different brands were collected from the Iranian bottled water databank. To comply with ethical considerations, the names of the brands are not mentioned, and each sample received a code from 1 to 71.

Fuzzy AHP and TOPSIS

The steps aimed to determine and prioritize different compounds and parameters affecting the quality of bottled water and, subsequently, to rank and determine the best brands. As noted before, this was performed by using fuzzy AHP and TOPSIS, the stages and steps of which are given below.

Step 1: Determining the criteria and sub-criteria (Delphi method)

We studied the health and esthetic effects of elements in drinking water by reviewing the WHO guideline and the literature. For each element, we then prepared a fact sheet including the health effects, the amount present in water, the pathways of the entrance to the water, and standards developed by international and national organizations.

The Delphi technique is a group decision-making process whereby expert opinions about a topic are collected and examined (Gumus 2009; Murry and Hammons 1995). In the first step, by using the Delphi method, we formed an expert panel consisting of 10 water quality experts from Tehran University of Medical Sciences to discuss the chemical and microbial parameters affecting the quality of bottled water. Based on each parameter's degree of importance and health-related effects (extracted from the guidelines of WHO, Environmental protection agency (EPA), and Iranian national standards) and upon examining similar studies on the parameters affecting the quality of water (EPA 2018; WHO 2017), seven main criteria and 44 sub-criteria (secondary criteria) were selected (Table 1).

Figure 1 presents the criteria in the form of a hierarchical diagram. The main and final objective (ranking bottled water quality) was placed at the first level of the decision hierarchy. The main indicators (chemical compounds related to esthetic effects, carcinogenicity, pathogenicity, toxicity, low-toxicity nutrients, those without health effects, and bacteriological agents) were placed at the next level. Secondary indicators were placed at the third level, and decision options (the bottled water brands) were placed at the final level.

Step 2: Completing the pairwise comparison questionnaire

A pairwise comparison questionnaire was developed based on the determined criteria and sub-criteria and completed by 10 water quality experts from various universities of Iran (Tehran, Shahid Beheshti, Semnan, and Hormozgan University of Medical Sciences) and the Tehran Province Water Organization. To fill out the questionnaires, first, the criteria had to be compared with each other, and then, the sub-criteria had to be compared and scored. The linguistic variables for performing pairwise comparisons were based on Table 2 (Saaty 1990; Sun 2010).

After developing the hierarchy, completing the questionnaires (by experts), performing pairwise comparisons of the criteria and sub-criteria, and allocating numeric scores, the data of each questionnaire were separately entered into Excel, and the final equivalent or combined matrices of expert opinions were prepared. The geometric mean was used to form the equivalent matrix (Eq. (1)).

$$\left(\prod_{i=1}^{n} a_i\right)^{\frac{1}{n}} = \sqrt[n]{a_1, a_2, \ldots, a_n} \tag{1}$$

Saaty proposed this method as the best technique for combining pairwise comparisons (Saaty 1986). The resulting pairwise comparison matrix is calculated as the geometric mean of all pairwise comparison matrices in the list of matrices. The unified fuzzy pairwise comparison matrix, consistency test of each matrix, the weight for each criterion, the best non-fuzzy performance (BNP) value for each weight, and finally the rank and priority of the criteria on the BNP values were examined and analyzed by the FuzzyAHP package version 0.9.0 in R software (Deng 1999; Ramík 2020). The obtained equivalent matrix was analyzed by FAHP, which is explained below to calculate the score of each criterion and sub-criterion.

Table 1 The selected main and secondary (sub-) criteria affecting bottled water quality and their definitions (EPA 2018; WHO 2017)

Main criteria	Sub-criteria	Definitions
Esthetically important chemical compounds	Al^{3+}, NH_4^+, Cl^-, hardness, Fe^{2+}, Mn^{2+}, Na^+, K^+, So_4^{2+}, Ca^{2+}, Mg^{2+}, HCO_3^-, Po_4^-, ALK, TDS, corrosion index, pH	Including parameters leading to esthetic effects (taste, color, smell, and sediments)
Carcinogenic chemical compounds	As^-, Pb^{2+}	Including definitive carcinogenic elements
Pathogenic chemical compounds	Cd^{2+}, Cr^{2+}, Hg^+, Ni^+, Ag^+, No_3^-, No_2^-	Including the elements, each of which causes a specific disease
Important chemical compounds in terms of toxicity	Sb^{3+}, V^{3+}, Tl^+, B^-, Co^{2+}	Including elements which lead to toxicity at high amounts
Important chemical compounds with low toxicity	Cu^{2+}, Se^-, Zn^{2+}, Sn^{2+}, Mo, Li^+, F^-	Including chemicals needed by the human body; however, if these chemicals exceed the permissible level, they will have undesirable effects on human health
Chemical compounds without health effects	Be^{2+}, Ba^{2+}, Sr^{2+}	Elements in this group are rarely found in drinking water. So far, no considerable health effect has been found for this group
Bacteriological agents	HPC, coliform, *Pseudomonas aeruginosa*	Including specific bacteria affecting the health of society

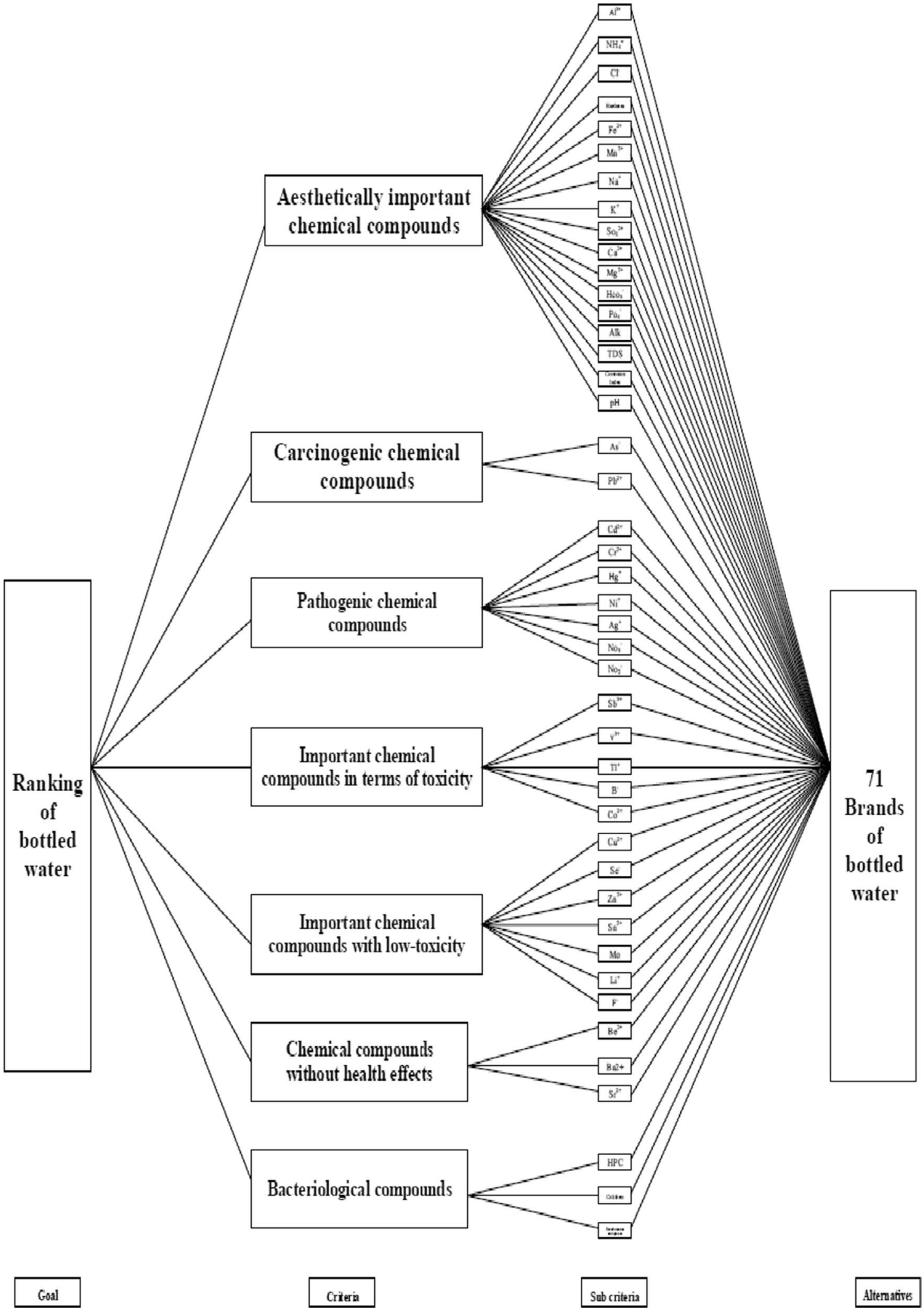

Fig. 1 Hierarchical diagram of selected criteria and sub-criteria for ranking bottled water quality

Table 2 Linguistic variables and triangular fuzzy numbers (TFN values)

TFN values	Crisp values	Linguistic variables
1, 1, 1	1	Equal
2, 3, 4	3	Not bad
4, 5, 6	5	Good
6, 7, 8	7	Very good
8, 9, 10	9	Perfect

Step 3: Determining the weight of the criteria (FAHP principles)

In this method introduced by Chang (1996), the level of each object is analyzed in the following stages via the fuzzy synthetic extent value (S_i) (Chang 1996):

Stage 1: $X = \{x_1, x_2, x_3, \ldots, x_n\}$ as a set of objects and G $= \{g_1, g_2, g_3, \ldots g_n\}$ as the objective. Thus, the analysis value of the level of M for each object will be in the form of Eq. (2), where $M^i_{g_i}(1,2,\ldots,m)$ denotes the triangular fuzzy numbers (l_i, m_i, u_i).

$$M^1_{g_i}, M^2_{g_i}, \ldots, M^m_{g_i} \quad i = 1,2,\ldots,n \tag{2}$$

Stage 2: The fuzzy synthetic extent value is calculated using Eqs. (3)–(6):

$$S_i = \sum\nolimits_{j=1}^{M} M^i_{g_i} \otimes \left[\sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1}^{m} M^j_{g_j}\right]^{-1}, \tag{3}$$

$$\sum\nolimits_{j=1}^{m} M^j_{g_i} = \left(\sum\nolimits_{j=1}^{m} l_j, \sum\nolimits_{j=1}^{m} m_j, \sum\nolimits_{j=1}^{m} u_j\right) \tag{4}$$

$$\sum\nolimits_{i=1}^{n} \sum\nolimits_{i=1}^{m} M^j_{g_i} = \left(\sum\nolimits_{i=1}^{n} l_i, \sum\nolimits_{i=1}^{n} m_i, \sum\nolimits_{i=1}^{n} u_i\right) \tag{5}$$

$$\left[\sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1}^{m} M^j_{g_i}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{6}$$

M_1 and M_2 are the triangular fuzzy numbers denoted by (l_1, m_1, u_1) and (l_2, m_2, u_2), respectively Fig. 2 (Saaty 1990).

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1, & if m_2 \geq m_1, \\ 0, & if l_1 \geq u_2, \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases}$$

The calculations were performed by using the aforementioned stages, and the degree of compatibility in the judgments was also calculated. The FuzzyAHP 0.9.0 package in R was employed to perform the final analysis and determine the best non-fuzzy performance (BNP) weight per main criterion and sub-criterion; in this way, the main criteria and sub-criteria were weighted. These weights were used to prioritize the criteria and also utilized in the next step and in TOPSIS for the final ranking of the bottled water brands.

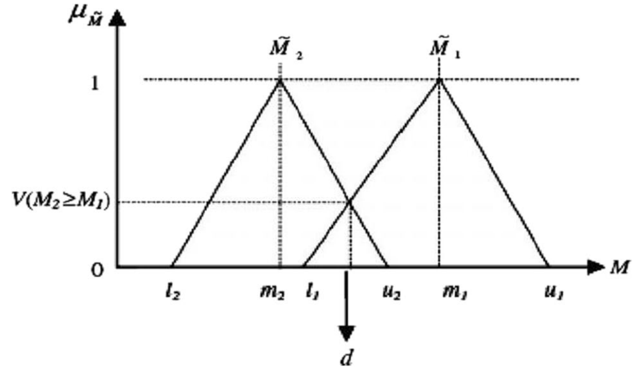

Fig. 2 The intersection between M_1 and M_2

Step 4: Final ranking (TOPSIS principles)

Stage 1: Forming the normalized matrix by the Euclidean norm method
The decision-making matrix was unscaled by using the Euclidean norm method. Each r_{ij} was calculated by dividing the corresponding entity in the primary matrix x_{ij} by the square root of the sum of squares of the elements of the corresponding column, as in Eq. (7) (Chen 2000).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{7}$$

Stage 2: Forming the weighted matrix (weighted unscaled matrix)
In this stage, to obtain the weighted unscaled matrix, the weight of the indicators was used as in Eq. (8).

$$v_{ij} = w_j \times r_{ij} \quad i = 1,2,\ldots,mj = 1,2,\ldots,n \tag{8}$$

Stage 3: Calculating the positive and negative ideals
Here, one positive (A^+) and one negative (A^-) ideal were calculated for each indicator, based on Eqs. (9) and (10).

$$A^+ = \{v_1^+, \ldots, v_n^+\} = \left\{\left(\underset{j}{max} v_{ij} | i \in I\right), (\underset{j}{min} v_{ij} | i \in J)\right\} \tag{9}$$

$$A^{-} = \{v_1^{-}, \ldots, v_n^{-}\} = \left\{ \left(\underset{j}{min} v_{ij} | i \in I \right), \left(\underset{j}{max} v_{ij} \right) | i \in j) \right\} \quad (10)$$

Sage 4: Calculating the distance of each option from positive and negative ideals

For each indicator, the distance between each option from the best (D_i^+) and worst (D_i^-) options was computed based on Eqs. (11) and (12). Here, v_{ij} and v_j are the positive and negative weighted unscaled matrix of each entity and the positive and negative ideal values of each indicator, respectively.

$$d_i^{+} = \left\{ \sum_{j=1}^{n} (v_{ij} - v_j^{+})^2 \right\}^{\frac{1}{2}} i = 1, \ldots, m \quad (11)$$

$$d_i^{-} = \left\{ \sum_{j=1}^{n} (v_{ij} - v_j^{-})^2 \right\}^{\frac{1}{2}} i = 1, \ldots, m \quad (12)$$

Stage 5: Calculating the ideal solution

By using Eq. (13), the relative proximity (CC_i) of each option to the ideal solution was calculated.

$$CC_i = \frac{d_i^{-}}{(d_i^{+} + d_i^{-})} i = 1,2, \ldots, m \quad (13)$$

Finally, by multiplying the CC_i, the final order and rank of all bottled water brands were obtained, and the best brand was selected based on all the effective criteria.

Results and discussion

All the FAHP and TOPSIS stages were followed in the FAHP 0.9.0 package in R and Microsoft Excel 2013. The degree of compatibility in the judgments in all the examined matrices was calculated and found to be < 0.1 (CR < 0.1). All the matrices were thus compatible, and the comparison results were stable. Table 3 lists the pairwise comparison matrix resulting from the expert opinions. For the other sub-criteria, a matrix similar to the following matrix was formed. Table 4 presents the output of R in terms of the weight obtained from each main criterion and sub-criterion.

The FAHP approach requires the pairwise comparison of the criteria and sub-criteria to determine relative weights.

Table 3 Unified fuzzy paired comparison matrix of main criteria

Relative weight	Esthetically important chemical compounds	Carcinogenic chemical compounds	Pathogenic chemical compounds	Important chemical compounds in terms of toxicity	Important chemical compounds with low toxicity	Chemical compounds without health effects	Bacteriological agents
Esthetically important chemical compounds	1, 1, 1	0.11, 0.11, 0.14	0.12, 0.13, 0.15	0.13, 0.14, 0.16	0.17, 0.21, 0.27	1.52, 1.99, 2.51	0.12, 0.14, 0.16
Carcinogenic chemical compounds	7.75, 8.75, 8.88	1, 1, 1	4.18, 5.33, 6.28	5.34, 6.43, 7.23	6.82, 7.83, 8.43	7.75, 8.75, 8.88	0.65, 0.88, 1.18
Pathogenic chemical compounds	6.60, 7.61, 8.32	0.16, 0.19, 0.24	1, 1, 1	0.71, 1.09, 1.64	3.32, 4.06, 4.70	6.73, 7.75, 8.27	0.66, 0.84, 1.08
Important chemical compounds in terms of toxicity	6.11,7.13,7.95	0.14, 0.16, 0.19	0.61, 0.92, 1.41	1, 1, 1	3.93, 5.04, 6.04	6.52, 7.54, 8.17	0.61, 0.78, 1.00
Important chemical compounds with low toxicity	3.75, 4.81, 5.85	0.12, 0.13, 0.15	0.21, 0.25, 0.30	0.17, 0.20, 0.26	1, 1, 1	4.52, 5.59, 6.48	0.20, 0.23, 0.27
Chemical compounds without health effects	0.40, 0.50, 0.66	0.11, 0.11, 0.13	0.12, 0.13, 0.15	0.12, 0.13, 0.15	0.15, 0.18, 0.22	1, 1, 1	0.12, 0.13, 0.14
Bacteriological agents	6.31, 7.33, 8.06	0.85, 1.14, 1.54	0.93, 1.20, 1.52	1.00, 1.29, 1.64	3.68, 4.34, 4.95	6.95, 7.97, 8.38	1, 1, 1

Table 4 Determining and ranking the weights of criteria and sub-criteria via the FAHP method

Main criteria	Original weight	Rank	Sub-criteria	Local weight	Overall weight	Rank
Esthetically important chemical compounds	0.026	6	Al^{3+}	0.13	0.00338	1
			NH_4^+	0.11	0.00286	2
			Cl^-	0.09	0.00234	4
			Hardness	0.04	0.00104	7
			Fe^{2+}	0.10	0.0026	3
			Mn^{2+}	0.10	0.0026	3
			Na^+	0.07	0.00182	5
			K^+	0.02	0.00052	10
			SO_4^2	0.05	0.0013	6
			Ca^{2+}	0.03	0.00078	9
			Mg^{2+}	0.04	0.00104	8
			HCO_3^-	0.3	0.00078	9
			PO_4^-	0.3	0.00078	9
			Alk	0.3	0.00078	9
			TDS	0.3	0.00078	9
			Corrosion index	0.05	0.0013	6
			pH	0.05	0.0013	6
			SUM	1	0.026	-
Carcinogenic chemical compounds	0.368	1	As^-	0.73	0.26864	1
			Pb^{2+}	0.27	0.09936	1
			SUM	1	0.368	-
Pathogenic chemical compounds	0.157	3	Cd^{2+}	0.26	0.04082	2
			Cr^{2+}	0.18	0.02826	3
			Hg^+	0.30	0.471	1
			Ni^+	0.10	0.0157	4
			Ag^+	0.06	0.00942	5
			NO_3^-	0.04	0.00628	6
			NO_2^-	0.06	0.00942	5
			SUM	1	0.157	-
Important chemical compounds in terms of toxicity	0.150	4	Sb^{3+}	0.36	0.054	1
			V^{3+}	0.13	0.0195	4
			Tl^+	0.21	0.0315	2
			B^-	0.19	0.0285	3
			Co^{2+}	0.11	0.0165	5
			SUM	1	0.150	-
Important chemical compounds with low toxicity	0.058	5	Cu^{2+}	0.17	0.00986	3
			Se^-	0.29	0.01682	1
			Zn^{2+}	0.09	0.00522	5
			Sn^{2+}	0.07	0.00406	7
			Mo	0.08	0.00464	6
			Li^+	0.1	0.0058	4
			F^-	0.2	0.0116	2
			SUM	1	0.058	-
Chemical compounds without health effects	0.020	7	Be^{2+}	0.42	0.0084	1
			Ba2 +	0.35	0.007	2
			Sr^{2+}	0.23	0/0046	3
			SUM	1	0.020	-

Table 4 (continued)

Main criteria	Original weight	Rank	Sub-criteria	Local weight	Overall weight	Rank
Bacteriological agents	0.22	2	HPC	0.09	0.0198	3
			Coliform	0.32	0.0704	2
			Pseudomonas aeruginosa	0.59	0.1298	1
			SUM	1	0.22	-

Equations (1)–(8) were used to calculate the weights of criteria and sub-criteria. According to the experts, the carcinogenic chemical compounds were the first and most important criterion affecting bottled water quality (Table 4). The order of the other main criteria was:

Carcinogenic chemical compounds > bacteriological agents > pathogenic chemical compounds > chemical compounds important in terms of toxicity > important chemical compounds with low toxicity > esthetically important chemical compounds > chemical compounds without health effects.

As noted before and based on Table 4, the category of carcinogenic compounds and its two sub-categories (lead and arsenic) had the first and most important place (with the weight of about 36.8%) among the qualitative factors affecting bottled water quality. Studies on the health effects of elements and their long-term health impact demonstrate the importance of these elements and, consequently, the necessity of controlling their maximum permissible value in consumable water (Gleason et al. 2019; Nigra et al. 2017).

Reports also demonstrate that many health risks attributed to drinking water in developing countries have a bacteriological origin. Moreover, 3.3% of the annual global mortality results from a lack of disinfected/treated water. Results of similar studies demonstrated that, by improving the bacteriological quality of drinking water, mortality resulting from water-borne diseases can be reduced by about 5% (Baumgartner and Grand 2006; Prasanth et al. 2019). Therefore, putting bacteriological factors with the weight of about 22% in the second place of the important and effective groups in this study indicates these parameters' significant health impact.

The elements belonging to the group of pathogenic chemical compounds (chromium, cadmium, mercury, nitrite, nitrate, etc.) have a bioaccumulation potential and cause specific diseases if they exceed the standard level. These compounds can explain the third rank of this group in this study (with a weight of about 15.7%) (Godt et al. 2006; Oehmen et al. 2006; Qiu and Zheng 2009).

Based on the literature, the elements in the group of chemical compounds significant in terms of toxicity (e.g., Sb^{3+}, V^{3+}, B^{-}, Co^{2+}) will have acute and chronic toxic impacts such as diarrhea, vomiting, weight loss, nervous system disorders, genetic mutations, and chromosomal anomalies if they exceed the standard levels (Peter and Viraraghavan 2005; Wuilloud et al. 2000; Yazbeck et al. 2005). Thus, in this study, these compounds with a weight of about 15% ranked fourth in terms of importance.

The elements belonging to the group of low-toxicity nutritious chemical compounds were within the ranges determined by international and national organizations for the general public. Nevertheless, since they can cause toxicity if they exceed the standard level, they ranked fifth in terms of importance (weight of about 5.8%) (Maheshwari 2006; Zietz et al. 2003).

Esthetically related chemical compounds can regulate smell, taste, sediments, color, and other esthetic factors; affect the acceptability of water by society; and do not have considerable health effects on the consumers. Based on the experts' opinions, these compounds received the weight of only about 2.6% and ranked sixth (Malakootian et al. 2010; Sarin et al. 2004).

Studies on the elements belonging to the group of chemical compounds without health effects (e.g., Be^{2+}, Ba^{2+}, Sr^{2+}) suggest that the presence and entry of these elements into water sources are insignificant, and no important health effect has yet been reported for them. This can explain why they received the coefficient of only 2% of the total weight and ranked the last in terms of importance (World Health Organization 1993).

The weight presented in Table 4 was the definitive and final (non-fuzzy) weight. The weight obtained in the last stage was used in the TOPSIS technique by using R and Excel for the final ranking of the brands. To this end, the relative distance of each option had to be measured. The option with the largest relative distance compared to the others ranks first. Table 5 presents the CC_i calculated by TOPSIS for all the studied brands.

Based on Table 5, Fig. 3, and the results of tests and experts' opinions, brands 2, 3, 1, 44, and 47 received scores of 0.679, 0.671, 0.645, 0.618, and 0.381, respectively, and were the best five brands of water, while brand 68 with the score of about 0.013 ranked the last. Tables S1 to S7 in the supplementary file provide a summary of the quality characteristics of each brand, which were the main basis for their scoring and ranking.

Although all the bottled water brands studied here are consumable, based on the roles of all the criteria and parameters

Table 5 CC_i and final rank of bottled water brands

No. brand	CC_i	Rank
1	0.645	3
2	0.679	1
3	0.671	2
4	0.349	8
5	0.367	7
6	0.344	10
7	0.380	6
8	0.215	19
9	0.210	22
10	0.183	26
11	0.343	11
12	0.240	17
13	0.214	20
14	0.186	24
15	0.182	27
16	0.080	44
17	0.144	33
18	0.184	25
19	0.075	49
20	0.081	43
21	0.178	29
22	0.064	52
23	0.150	32
24	0.096	41
25	0.044	60
26	0.188	23
27	0.179	28
28	0.048	56
29	0.116	34
30	0.039	62
31	0.062	53
32	0.154	31
33	0.231	18
34	0.115	35
35	0.076	48
36	0.110	38
37	0.061	54
38	0.071	51
39	0.083	42
40	0.105	39
41	0.214	21
42	0.055	55
43	0.047	57
44	0.618	4
45	0.319	13
46	0.104	40
47	0.381	5
48	0.171	30
49	0.079	45
50	0.318	14
51	0.047	58
52	0.113	36
53	0.047	59
54	0.348	9
55	0.076	47
56	0.018	70
57	0.072	50
58	0.27	16
59	0.034	65
60	0.027	67
61	0.113	37
62	0.337	12
63	0.035	64
64	0.078	46
65	0.042	61
66	0.283	15
67	0.024	69
68	0.013	71
69	0.036	63
70	0.024	68
71	0.028	66
-	-	-

affecting the selection of the best brand (examining the roles of the seven main criteria and 44 secondary criteria), a significant difference was perceived in their quality. This necessitates further examinations and the use of multiple-criteria decision-making techniques, not merely for bottled water brand ranking and selection, but also in all managerial and decision-making domains.

Conclusion

The quality assessment and selection of the best bottled water brand are difficult due to the effect of various physical (temperature and turbidity), chemical (heavy metals, anions, and cations), and bacteriological (*Pseudomonas* and coliforms) parameters on water quality and the existence of numerous brands in the market. Herein, by using the MCDM method (FAHP-TOPSIS), the quality of 71 bottled water brands in the Iranian market was ranked. The application of MCDM approaches in various sciences indicates these methods' strong capability in evaluating problems that possess multiple criteria. These methods accurately assess bottled water quality and aid the customer in selecting a higher-quality brand. They can, therefore, be adopted to create competition among manufacturers to produce higher-quality products. In this study, the grouping and weighting of elements were based on the opinions of Iranian experts and by taking into account the local conditions of Iran. For global applications,

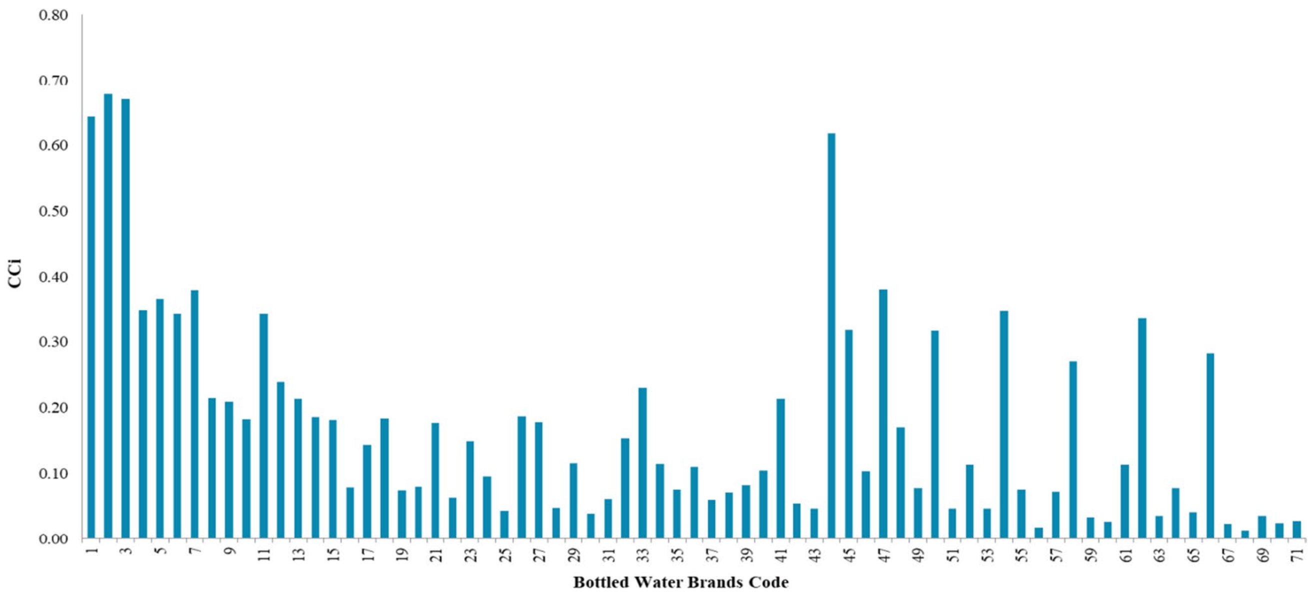

Fig. 3 Ranking of 71 brands of bottled water

a comprehensive model can be proposed for water quality assessment by considering other chemical and bacteriological parameters affecting water quality and with the participation of international experts from other countries.

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Availability of data and materials The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval The study was approved by the ethical committee of Tehran University of Medical Sciences. Ethics code: IR.TUMS.SPH.REC.1397.277.

Consent to participate All authors duly participated.

Consent to publish All authors hereby consent to publish this manuscript.

Competing interests The authors declare no competing interests.

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