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Evaluating and selecting the best domestic water standards

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ABSTRACT

Water quality standards describe a specific quality of water, which can be identified as a reliable source for choosing water. Everyone in the world needs access to clean water, which can be evaluated by drinking water standards. The purpose of the standards is to ensure the quality and safety of water for drinking. Additionally, determining the criteria for choosing the best possible standard is essential for water consumers. The fuzzy multi-criteria decision-making process was introduced in the early '70s along with the initiation of the fuzzy set theory. This theory is well-integrated with the decision-making process and as a result, has created many new multifunctional decision methods. Therefore, this tool can be used to evaluate a variety of factors in order to make better and more efficient decisions. In this research, five different water quality standards for fuzzy multi-purpose decision-making have been selected to evaluate their performance. The Gaussian preference function was used for the comparison of water quality standards after the collection of significant parameters for each criterion, which is useful in analyzing water quality standards. These parameters were imputed into the PROMETHEE approach. According to the selected criteria and their weights, it was found that the European Union (E.U.) standard has greater reliability capability in providing safer drinking water compared to other standards.

Keywords: Fuzzy multi-criteria decision making; PROMETHEE; Water quality standards; Quality index

1. Introduction

Water is the most essential source for the sustenance of human and animal life. Water quality combines the physical, chemical, and biological properties of the water [1]. Major sources of water include rivers, lakes, glaciers, rainwater, and groundwater. Besides consumption, water also serves other purposes, which may include agricultural, industrial, hydropower generation, and creative purposes. Since the beginning of the intense industrialization of the world in the 21st century, the quality of water from natural sources has been contaminated [2]. This involves the contamination of water bodies with industrial waste and the accidental introduction of agricultural chemicals such as herbicides,

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pesticides, etc. [2]. Also, inadequate water resources have progressively limited water contamination control and water quality improvement [3]. Water contamination has been the focus of investigation for governments and researchers. Subsequently, ensuring river water quality is very important because of the worldwide shortage of water resources. The freshwater environments of the world cover approximately 0.5% of the world's surface and have a volume of 2.84 $km^3 \times 105$ km^3 [4]. Rivers only constitute (0.1%) of the land surface, yet water is of great significance [4]. Changes in the physicochemical attributes of water quality are impacted by anthropogenic variables [5].

The U.S Environmental Protection Agency (EPA) controls the level of Contamination in water provided by US public water systems. Two types of standards proposed by EPA:

- Elemental standards that limits the materials that possibly threats human health [6] and [7];
- Secondary standards that describe esthetic qualities, like affect on taste, odor, or appearance [8].

In Europe, the European Drinking Water Directive sets water quality standards, while in the United States, the United States EPA controls and monitors standards in terms of meeting the requirements of the Safe Drinking Water Act. For countries that do not have an official framework for such standards, the World Health Organization (WHO) has established guidelines for the standards to be met [9]. China has a specific drinking water standard, namely GB3838-2002 (Type5 II), which was prepared by the Ministry of Environmental Protection in 2002. Where drinking water quality standards are found, they are predominantly considered as guidelines or tasks rather than requirements [10]. There are two exceptions, which are the European Drinking Water Directive and the Safe Drinking Water Act in the United States of America, which requires particular standard properties. In Europe, this includes a requirement for each European country to develop appropriate local standards to guide the principles in the country. In other countries such as Canada, there is a standard that exists as a guideline for drinking water. However, countries such as New Zealand and Australia depend on standards that require all water suppliers to strictly follow the legislative guidelines [11].

Quality standards for drinking water depend on the climatic conditions of each region, which can sometimes be a challenge. Regarding this issue, fuzzy PROMETHEE was used to choose between five main standards used in different countries.

1.1. World Health Organization

The WHO, based in Geneva, Switzerland, is a specialized United Nations agency dealing with international public health that was founded on April 7, 1948. Its predecessor, the health organization, was formed under the League of Nations [12]. Sixty-one countries signed the WHO constitution on July 22, 1946, when the first assembly of the world health ended. Since its foundation, it has actively contributed to the eradication of smallpox. Some of the current priorities of the WHO include controlling infectious diseases, especially Tuberculosis, Malaria, Ebola, and HIV/AIDS, food security, healthy food, substance abuse, occupational health, and leadership in the development of reports, publications, networking, etc. [13].

1.2. European union

The EU has recorded more than three decades of drinking water regulations; these regulations guarantee that water is safe for human consumption [15]. The basic pillars of the regulations are to:

- Guarantee scientific-based quality monitoring of drinking water quality.
- Ensure good monitoring, enforcement, and assessment of drinking water quality.
- Provide consumers with sufficient, appropriate, and timely information.
- Contribute to the EU's broader health and water policies.

1.3. Australia

Quality standards for drinking water were prepared by the Australian National Council for Health and Medical Research (NHMRC) in the form of Australian guidelines of drinking water [16]. These guidelines limit contamination factors including aesthetic, pathogen, inorganic, organic, and radiological. Guidelines present limits on contamination levels (such as pathogen, aesthetic, organic, inorganic, and radiological).

1.4. The U.S.

In the United States, the federal legislation governing the quality of drinking water is the Safe Drinking Water Act (SDWA), which is implemented by the EPA, primarily through state or regional priority agencies. States and regions should apply the guidelines provided by the EPA in order to maintain primary enforcement authority (priority) over drinking water. Many states may establish and apply their own local standards, which could be more stringent. These local standards must be adaptable to the guidelines of the EPA in the USA. Moreover, other nations may also use the US EPA guidelines as an acceptable and reliable standard for monitoring and controlling safe water for consumption [17].

1.5. Canada

The Canadian drinking water quality guidelines and technical guidance documents (formerly known as supporting documentation) have been developed by the Federal Regional Committee for drinking water and were published by the Canadian Health Organization in 1968. Canadian supplies of drinking water have excellent quality. However, natural water is not completely pure. It incorporates aspects of everything that comes in its way, such as fertilizers, minerals, vegetation, silt, and runoff. While most of these materials are considered harmless, some are hazardous for health [18]. To address this risk, the Canadian Health Organization works with the local governments around the country to provide guidelines that determine the maximum acceptable concentrations of these materials in drinking water. These drinking water regulations are prepared to ensure healthy water for the most vulnerable society members, like the elderly and children. Guidelines define the basic criteria that each water system must work hard to achieve for providing cleaner, safer, and more reliable drinking water. Understanding and meeting the regulations is essential in an approach with many barriers to drinking water with safe quality. This approach is considered in every drinking water supply system from the source through to the consumer; these guidelines can be used as mark points to ensure that barriers work and that treated drinking water is clean and drinkable. Canadian drinking water quality guidelines deal with chemical, radiological, and microbiological contaminations. They also address concerns about the physical properties of water, such as taste and color.

2. Fuzzy PROMETHEE (F-PROMETHEE)

Brans and Vincke [19] developed the PROMETHEE procedure for making decisions where various alternatives exist. The procedure is based on comparing a pair of alternatives with respect to the selected criteria. The model is one of the less complicated among many multi-criteria decision-making tools in terms of application and conception [20–25]. This method can be used for real-world multi-criteria decision-making problems even where a conflicting criterion exists. PROMETHEE I provide a partial ranking of the alternatives and PROMETHEE II gives a complete ranking of the alternatives. This technique ranks the alternatives based on the differences between pairs of each alternative in terms of each criterion. In order to process this analysis, the importance weights of the criteria, and the preference function associated with each criterion are needed. The preference function (P_j) is the evaluation (in scores) of the two alternatives a_t and $a_{t'}$ within the system into a preference degree ranging from 0 to 1 for each specific criterion. Different types of preference functions are available for the PROMETHEE method including the *V*-shape function, level function, usual function, *U*-shape function, linear function, and Gaussian function, which can affect the ranking results [26].

The basic steps involved in the PROMETHEE method are as follows [24]:

- *Step* 1. For each particular criterion represented as *j*, a specific preference function denoted as $p_j(d)$ is determined.
- *Step* 2. For each particular criterion, its weight is represented as $w_T = (w_1, w_2, \ldots, w_k)$. If the relative importance of the criteria is equal, then the weights can be equal.
- *Step* 3. The outranking relation of the alternatives within the system where a_t and $a_{t'} \in A$ has been defined by π and can be calculated using the following formula:

$$\pi\left(a_t, a_{t'}\right) = \sum_{k=1}^{K} w_k \cdot \left[p_k\left(f_k\left(a_t\right) - f_k\left(a_{t'}\right)\right)\right], AXA \rightarrow \left[0,1\right] \quad (1)$$

Here, π (*a*, *b*) stands for the preference index and *k* represents the selected criteria. The preference index is a measure that indicates the intensity of preference in the multi-criteria decision-making method for the alternative a_t in comparison to alternative $a_{t'}$ considering all criteria at the same time.

- *Step* 4. Determination of the leaving and entering outranking:
  - Leaving (or positive) flow for the alternative a_t:

$$\Phi^+\left(a_t\right) = \frac{1}{n-1} \sum_{\substack{t'=1 \\ t' \neq t}}^{n} \pi\left(a_t, a_{t'}\right) \quad (2)$$

  - Entering (or negative) flow for the alternative a_t:

$$\Phi^-\left(a_t\right) = \frac{1}{n-1} \sum_{\substack{t'=1 \\ t' \neq t}}^{n} \pi\left(a_{t'}, a_t\right) \quad (3)$$

Here, *n* stands for the number of alternatives. A comparison is made with each particular alternative to (*n*–1) the number of other alternatives present within the system. The leaving flow denoted as $\Phi^+(a_t)$ indicates the strength of an alternative represented as $a_t \in A$. On the other hand, the entering flow presented as $\Phi^-(a_t)$ indicates the weakness of the alternatives in $a_t \in A$. The strength of the alternatives is calculated through the positive and negative outranking flows. The positive outranking flow is an aggregated outranking sum of each alternative compared to the alternatives over all the criteria, whereas the negative outranking flow indicates the measure of weakness of the alternative over other alternatives with all the criteria. This is presented in Fig. 1. For the complete ranking of the alternatives, net outranking flow is calculated, which is the difference between the positive and negative outranking of each alternative.

In Fig. 1, the positive outranking flow denoted as $\Phi^+(a_4)$ was used to calculate the positive outranking flow through the average of the outranking of each alternative compared to the alternatives over all the criteria. Negative outranking flow presented as $\Phi^-(a_4)$ was used to calculate the negative outranking flow for each alternative in order to measure the weakness of that alternative compared to other alternatives with all the criteria. In this study, there were five drinkable water standards to be compared with each other. However, this figure only represents four alternative comparisons. Here, alternatives are indicated as "a_i" where i = 1,2,3,4.

Subsequent to the outranking flow, PROMETHEE I evaluates the partial order of the alternatives and PROMETHEE II evaluates the complete order based on the net flow.

- *Step* 5. Determination of the partial order of the alternatives.

The alternative with a higher positive outranking flow and lower negative outranking is preferred to the other alternatives. With an equal negative outranking flow, the higher positive outranking alternative is preferred. Lastly, with equal positive outranking, one should prefer the alternative with the lower negative outranking flow. Alternative a_t in PROMETHEE I is preferred over alternative $a_{t'}$ $\left(a_t P a_{t'}\right)$ if it satisfies one of the conditions presented below:

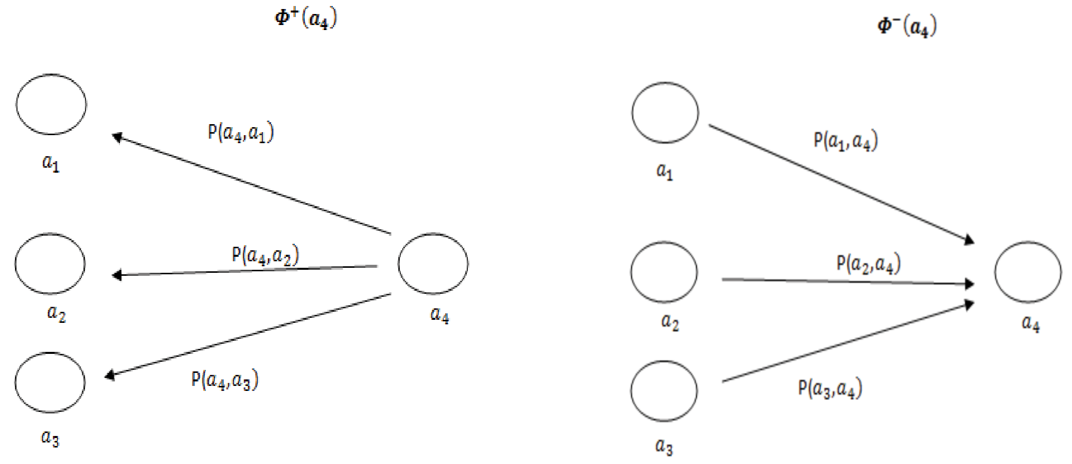

Fig. 1. PROMETHEE outranking flows.

$\left(a_t P a_{t'}\right)$ *if* :

$$\begin{cases}\Phi^+\left(a_t\right) > \Phi^+\left(a_{t'}\right) \text{ and } \Phi^-\left(a_t\right) \le \Phi^-\left(a_{t'}\right) \\ \Phi^+\left(a_t\right) = \Phi^+\left(a_{t'}\right) \text{ and } \Phi^-\left(a_t\right) < \Phi^-\left(a_{t'}\right)\end{cases} \tag{4}$$

where a_t is indifferent to $a_{t'}\left(a_t I a_{t'}\right)$ when the two alternatives a_t and $a_{t'}$ have similar entering and leaving flows:

$$(a_t I a_{t'}) \text{ if} : \Phi^+\left(a_t\right) = \Phi^+\left(a_{t'}\right) \text{ and } \Phi^-\left(a_t\right) = \Phi^-\left(a_{t'}\right) \tag{5}$$

When one alternative has a higher positive outranking flow and higher negative outranking flow, or a lower positive outranking flow, and lower negative outranking flow, it is hard to compare the alternatives. With the function below, such situations are defined as incomparable with PROMETHEE I.

a_t is incomparable to $a_{t'}$ $\left(a_t R a_{t'}\right)$ if:

$$\begin{cases}\Phi^+\left(a_t\right) > \Phi^+\left(a_{t'}\right) \text{ and } \Phi^-\left(a_t\right) > \Phi^-\left(a_{t'}\right) \\ \Phi^+\left(a_t\right) < \Phi^+\left(a_{t'}\right) \text{ and } \Phi^-\left(a_t\right) < \Phi^-\left(a_{t'}\right)\end{cases} \tag{6}$$

To overcome this issue, PROMETHEE II was used, which gives a net outranking flow in incomparable situations in PROMETHEE I.

- *Step* 6. Determination of the net outranking flow for each particular alternative by the formula represented below:

$$\Phi^{\text{net}}\left(a_t\right) = \Phi^+\left(a_t\right) - \Phi^-\left(a_t\right) \tag{7}$$

A complete order determined via net flow can be obtained by PROMETHEE II, as shown below:

$$a_t \text{ is preferred to } a_{t'} \left(a_t P a_{t'}\right) \text{ if } \Phi^{\text{net}}\left(a_t\right) > \Phi^{\text{net}}\left(a_{t'}\right) \tag{8}$$

$$a_t \text{ is indifferent to } a_{t'} \left(a_t I a_{t'}\right) \text{ if } \Phi^{\text{net}}\left(a_t\right) = \Phi^{\text{net}}\left(a_{t'}\right) \tag{9}$$

The higher the Φ^{net} (a_t) value, the better is the alternative (15,16).

Fuzzy logic is a form of many-valued logic that was created by Zadeh [27] in 1984, which has many successful hybrid applications in various fields [27–31]. The fuzzy PROMETHEE combines both PROMETHEE and fuzzy logic. This hybrid method allows the decision-maker to use vague information such as missing data, insufficient data, or the linguistic data about the feature of the alternatives and the importance weights during the multi-criteria decision-making process. However, the experiences of the decision-makers or the experts also can be added to the model via the fuzzy sets. This technique aims to obtain the differences between the fuzzy sets. The method was recommended for comparing non-numeric alternatives by Wang et al. [32]. Collecting satisfactory data to fully examine a problem and making an appropriate decision is sometimes difficult in real life. However, with fuzzy sets, the decision-maker is able to examine the system in a fuzzy condition, which is practical. Uzun Ozsahin et al. [22] provided a detailed discussion of the fuzzy PROMETHEE method that is used in this paper. Yager defined an index (YI) to compare the triangular fuzzy sets based on the center of weights of the surface of the triangular membership function. The Yager index can be calculated using Eq. (10) as shown below:

$$\text{YI} = \frac{\left(3N - a + b\right)}{3} \tag{10}$$

where a triangular fuzzy set is defined as $\tilde{F} = \left(N, a, b\right)$ or equivalently $\tilde{F} = \left(N - a, N, N + b\right)$.

The fuzzy scale in Table 2 was used to compare the defined criteria of the water standards methods effectively in order to obtain the significance of each criterion. The Yager index was employed to defuzzify the triangular fuzzy numbers to obtain the weight of each criterion [23]. In order to solve conflicts arising between the experts while giving the importance weights between the range [0,1], the fuzzy sets based on the linguistic data were used.

After gathering the parameters for the comparison of the flexible drinkable water standards, the Gaussian preference

Table 1
Chemicals of health significance as described by the World Health Organization guidelines (WHO) for drinking-water quality in the 3rd edition (2008) and 4th edition (2011) [14]

Parameter	Unit	WHO 3rd edition (2008) [14]	Latest WHO 4th edition (2011) [14]
Acrylamide	μg/L	0.5	0.5
Alachlor	μg/L	20	20
Aldicarb	μg/L	10	10
Aldrin and Dieldrin	μg/L	0.03	0.03
Antimony		0.02	0.02
Arsenic		0.01 (*P*)	0.01 (*A*,*T*)
Atrazine		2	100
Barium		0.7	0.7
Benzene	μg/L	10	10
Benzo[a]pyrene	μg/L	0.7	0.7
Boron	μg/L	0.5 (*T*)	2.4
Bromate	μg/L	10 (*A*,*T*)	10 (*A*,*T*)
Bromodichloromethane	μg/L	60	60
Bromoform	μg/L	100	100
Cadmium		0.003	0.003
Carbofuran	μg/L	7	7
Carbon tetrachloride	μg/L	4	4
Chlorate	μg/L	700 (*D*)	700 (*D*)
Chlordane	μg/L	0.2	0.2
Chlorine		5 (*C*)	5 (*C*)
Chlorite	μg/L	700 (*D*)	700 (*D*)
Chloroform	μg/L	300	300
Chlorotoluron	μg/L	30	30
Chlorpyrifos	μg/L	30	30
Chromium		0.05 (*P*)	0.05 (*P*)
Copper		2	2
Cyanazine	μg/L	0.6	0.6
Cyanide		0.07	–
Cyanogen chloride		0.07	–
2,4-D (2,4-dichlorophenoxyacetic acid)	μg/L	30	30
2,4-DB (2,4-dichlorophenoxybutyric acid)	μg/L	90	90
DDT (Dichlorodiphenyltrichloroethane) and metabolites	μg/L	1	1
Di (2-ethylhexyl) phthalate	μg/L	8	8
Dibromoacetonitrile	μg/L	70	70
Dibromochloromethane	μg/L	100	100

With respect to WHO drinking-water quality 3rd edition (2008) [14]: *P* = value of the provisional guideline; *T* = value of provisional indication because the calculated guidance is lower than the achievable value through practical processing methods and protection of the source; *C* = Material concentrations at or below the healthy indicative value, which could have an impact on the appearance or taste of the substance. With respect to WHO drinking-water quality 4th edition (2011 [14]): *A* = temporary value of indication as calculated guidance value is less than achievable quantitative level; *C* = materials concentration at or below the healthy indicative value could have an impact on appearance or taste of the substance; *P* = temporary value indication because of uncertainty in the database of health; *T* = provisional indicative value.

function was utilized for each criterion, as presented in Table 2. However, *U*-shape and linear preference functions were also used for obtaining the ranking results of the drinkable water standards. The Visual PROMETHEE decision lab program was then applied.

3. Result and discussion

In order to analyze the drinkable water standards, fuzzy based PROMETHEE technique has been applied. For choosing the best option among alternatives, the examination of each criterion is considered. The simultaneous selection of criteria could be a difficult task due to the sensitivity of the subject. Drinking water is one of the most important things in human life as it has a direct impact on health. After the investigation and the analysis of the existing criteria, the standards were introduced to the fuzzy PROMETHEE simulation as analytical identifiers data. However, depending on the definition of the criteria, different choices can also be made. Considering that 15 criteria were chosen from drinking water standards and assigned with weights and values regarding their importance, the results were generated by the Visual PROMETHEE decision lab program, as seen in Tables 4 and 5. The results show the complete ranking of drinking water standards with respect to the selected criteria. The results show that the E.U. has the most reliable standard for monitoring and controlling drinking water followed by the Canadian water quality standard. However, the U.S. standard was ranked the least alternative.

The positive outranking flow is a value that shows the strength of the alternative drinkable water standards, and the negative outranking flow shows the weakness of the

Table 2
Linguistic fuzzy scale

Linguistic scale for evaluation	Triangular fuzzy scale
Very high (VH)	(0.75, 1, 1)
Importance (H)	(0.5, 0.75, 1)
Medium (M)	(0.25, 0.50, 0.75)
Low (L)	(0, 0.25, 0.5)
Very low (VL)	(0, 0, 0.25)

Table 3
Visual PROMETHEE for selection of best water standard

	1,2-Dichlorobenzene	1,2-Dichloroethane	1,4-Dichlorobenzene	2,4-D	Aldicarb
Aim	Minimum	Minimum	Minimum	Minimum	Minimum
Values	Maximum	Maximum	Maximum	Maximum	Maximum
Weight	0.92	0.75	0.75	0.5	0.92
WHO	1	0.03	0.3	0.03	0.01
EU	0.0001	0.003	0.0001	0.0001	0.0001
Australia	1.5	0.003	0.04	0.0001	0.001
US	0.6	0.005	0.075	0.07	0.003
Canada	0.2	0.005	0.005	0.1	0.009
	Antimony	Arsenic	Atrazine	Barium	Benzene
Aim	Minimum	Minimum	Minimum	Minimum	Minimum
Values	Maximum	Maximum	Maximum	Maximum	Maximum
Weight	0.75	0.92	0.5	0.75	0.92
WHO	0.02	0.01	0.002	0.7	0.01
EU	0.005	0.01	0.0001	0.0001	0.001
Australia	0.003	0.007	0.0001	0.7	0.001
US	0.006	0.01	0.003	2	0.005
Canada	0.006	0.01	0.005	1	0.005
	Benzo[a]pyrene	Bromate	Cadmium	Carbofuran	Carbon tetrachloride
Aim	Minimum	Minimum	Minimum	Minimum	Minimum
Values	Maximum	Maximum	Maximum	Maximum	Maximum
Weight	0.92	0.75	0.75	0.75	0.75
WHO	0.0007	0.01	0.003	0.007	0.007
EU	0.00001	0.01	0.005	0.0001	0.004
Australia	0.00001	0.02	0.002	0.005	0.0001
US	0.0002	0.01	0.005	0.04	0.003
Canada	0.00001	0.01	0.005	0.09	0.005
	Chlorpyrifos	Chromium	Cyanide	Dichloromethane	Dimethoate
Aim	Minimum	Minimum	Minimum	Minimum	Minimum
Values	Maximum	Maximum	Maximum	Maximum	Maximum
Weight	0.75	0.5	0.75	0.75	0.75
WHO	0.03	0.05	0.07	0.02	0.006
EU	0.0001	0.05	0.05	0.05	0.0001
Australia	0.01	0.05	0.08	0.004	0.05
US	0.003	0.1	0.2	0.005	0.005
Canada	0.09	0.05	0.2	0.05	0.02

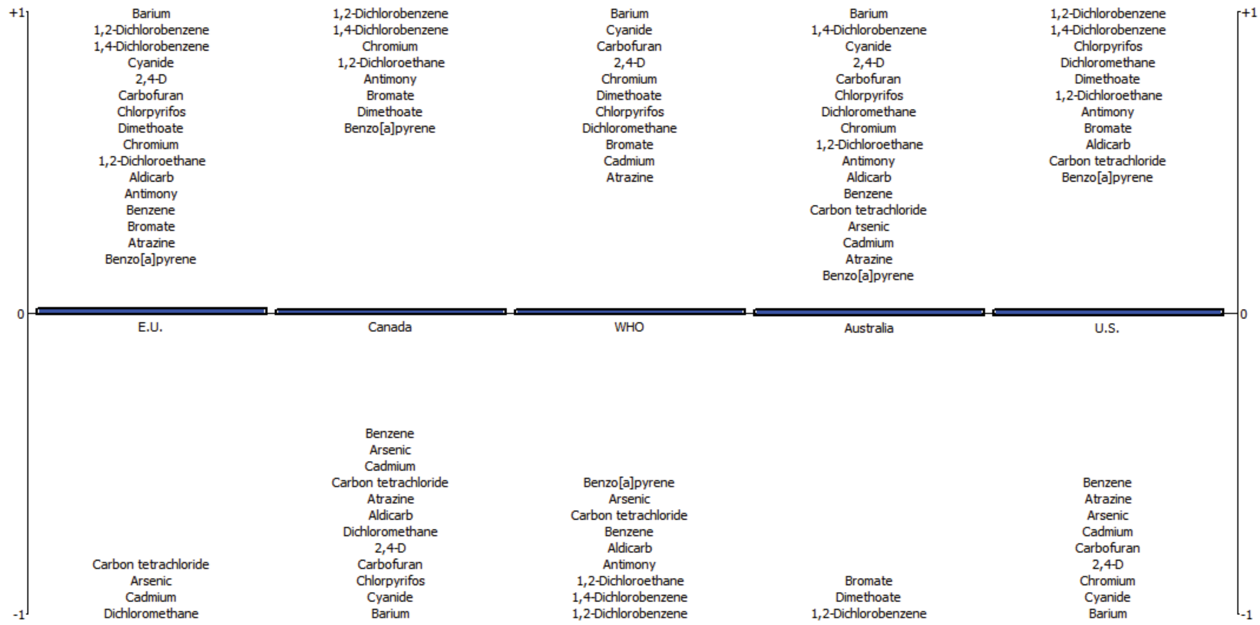

Fig. 2. Evaluation of drinkable water standards.

Table 4
Complete ranking of drinkable water standards with Gaussian preference functions

Ranking	Water	Positive outranking flow	Negative outranking flow	Net flow
1	E.U.	0.0068	0.0000	0.0068
2	Canada	0.0027	0.0009	0.0018
3	WHO	0.0014	0.0020	–0.0006
4	Australia	0.0012	0.0043	–0.0031
5	U.S.	0.0008	0.0058	–0.0049

Table 5
Complete ranking of drinkable water standards with *U*-shape preference functions

Ranking	Water	Positive outranking flow	Negative outranking flow	Net flow
1	E.U.	0.0276	0.0000	0.0276
2	Canada	0.0152	0.0000	0.0152
3	WHO	0.0124	0.0000	0.0124
4	Australia	0.0124	0.0305	–0.0180
5	U.S.	0.0000	0.0373	–0.0373

alternative drinkable water standards. Net flow is the difference between the positive and negative outranking flow and the higher net flow is the most preferred option. With a net flow value of 0.0068, the E.U. drinkable water standard is the best option among the other alternatives according to the given weight to each criterion, while the U.S. drinkable water standard has the lower net flow. However, the E.U standard is determined to be the best drinkable water standard, while the U.S. standard is the least one by using the linear preference function. In this study the Gaussian preference function has been proposed since it takes into account the standard deviation while giving priorities to the alternatives.

4. Conclusion and recommendations

In this research, the most preferred domestic water standard has been recommended. The analysis has been made between the water standards of developed countries with respect to their properties using one of the most important multi-criteria decision techniques, namely the fuzzy PROMETHEE method. The selection of these alternative water standards was obtained with the weight given to their parameters determined by the opinions of experts. The weights of the parameters also can be modified with respect to the needs of the decision-makers. The results of this study show that the E.U. water standard is more effective because of its low parameters.

Presently, the E.U. is recommended as the best option due to its cost-effectiveness and other advantages. Also, other standards have their advantages and disadvantages, which have been shown in Fig. 1. The fuzzy PROMETHEE technique has been applied to select the best standards amongst the five most common water quality standards used in various parts of the world. The selection was based on the allowable concentration of the contaminants present in the water. The E.U. standard was found to provide higher quality potable water and should, therefore, be adopted by all countries for protection against most water-related health issues based on the importance weights of the criterion.

Additionally, it is recommended that evaluating all the criteria with different weights according to the local needs could lead to a better practical ranking result.

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