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The optimal dam site selection using a group decision-making method through fuzzy TOPSIS model

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Abstract
The complex and controversial task of selecting a dam site in a river basin can be successfully achieved using science-informed multi-criteria decision-making (MCDM) techniques. In this paper, we describe the application of the group fuzzy TOPSIS model for optimal ranking of the case study of Kandoleh dam sites in Kermanshah province, Iran, involving 18 input criteria. In this study, decision-making committee was made up of 20 involved decision makers. The comments of four non-biased, external experts in dam site selection were also used. The triangular fuzzy numbers were used to apply experts' opinions on the selection criteria. In total, four alternative sites were assessed based on the technical, economic, social and environmental considerations and the data were analyzed using fuzzy TOPSIS MCDM model. Ranking results were compared with multi-criteria decision-making models, including the ELimination and Choice Expressing the REality and simple additive weighting. This logical, open and transparent framework provides a science-informed decision-making approach for complex problems such as optimal dam site selection. Finally, using sensitivity analysis, local studies and group discussions, we demonstrated the multiple benefits of the proposed novel method for a science-informed, open and transparent method for optimal ranking of the dam site candidates.

Keywords TOPSIS · MCDM · Optimal ranking · Water resource · Kandoleh dam

1 Introduction

Multi-criteria decision-making method (MCDM) is the one through which multiple and conflicting matters are investigated (Wang et al. 2009; Kurth et al. 2017; Cegan et al. 2017). In other words, MCDM method is the process of finding an optimal alternative among all feasible options (Tecle et al. 1988; Weng et al. 2010). In recent years, utilizing the analytic techniques of multi-criteria decision making in complicated problems has increased. This per-se is set to help researchers in informing and improving scientific works as well as future investments (Zyoud and Fuchs-Hanusch 2017). Mentioned method is employed in many fields, ranging from social and medical science to engineering, computer sciences and management information (Srdjevic and Medeiros 2008; Kahraman et al. 2015).

To date, diverse methods of solving decision-making problems have been presented including analytic hierarchy process (AHP) method (Satty 1980), technique for order preference by simulation of ideal solution (TOPSIS) method (Yoon and Hwang 1995; Mousavi et al. 2012), Elimination Et Choice Translating REality (ELECTRE) method (Benayoun et al. 1966; Netto et al. 1996), analytic network process (ANP) method (Saaty 1996) and Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method (Opricovic and Tzeng 2002; Kahraman et al. 2003) resulting from MCDM model. TOPSIS method is known as one of the most popular methods among MCDM techniques so that using attribute information in this method will result

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in alternatives ranking (Chen and Hwang 1992; Yoon and Hwang 1995).

The TOPSIS method was initially developed by Hwang and Yoon (1981) (Yoon and Hwang 1995). Chen and Hwang (1992) applied fuzzy numbers to establish fuzzy TOPSIS. Chen (2000) expanded TOPSIS method for decision-making problems to the fuzzy environment using vertex method in which it is possible to calculate both fuzzy members. Wang and Chang (2007) proposed a fuzzy TOPSIS method and used it to select a training plane. Wang and Lee (2007) developed TOPSIS method to the fuzzy environment and concluded that by applying Up and Lo operators, this approach could be readily generalized and other problems, for instance, fuzzy multi-criteria group decision making (FMCGDM), can be solved efficiently. Zyoud and Fuchs-Hanusch (2017) studied TOPSIS and AHP methods to investigate and analyze the bibliometric performance indicators in multi-criteria decision-making problems.

Since rural and urban areas are under the influence of water resource-related matters, the investigation of water resource management which leads to efficient and accurate methods appears essential. In recent years, decision-making methods with multiple MCDM indicators have been considered by researchers through which a solution among existed remedies or solutions ranking is suggested (Weng et al. 2010; Okeola and Sule 2012).

Hence, extensive studies have been carried out by researchers to exploit and manage various aspects of water resources management. Tzimopoulos et al. (2013) described the process of selecting a dam site according to fuzzy TOPSIS method as a multi-criteria decision-making problem. For this, determining an optimal solution among all alternatives was made by choosing involved criteria and in following obtained ranking was compared with Shannon entropy method (Gazendam et al. 2009; Atieh et al. 2015, 2017). Kodikara et al. (2010) utilized PROMETHEE method in evaluating Melbourne water supply system in which three major groups in decision-making and eight performance measures were considered to obtain alternatives ranking.

Optimal location of a dam site is one of the most complicated issues of MCDM in water resource management associating with considerable uncertainty due to the existence of qualitative criteria. TOPSIS is one of the popular MCDM models that can deal with this problem (Chen and Hwang 1992; Yoon and Hwang 1995), and hence, it was adopted for this study. This technique is based on a concept that the optional alternative should have the shortest and farthest distance from fuzzy positive ideal solutions (FPIS) (the best possible state) and fuzzy negative ideal solutions (FNIS) (the worst possible state), respectively (Roghanian et al. 2010). This paper is one of the first applications of fuzzy TOPSIS method for optimal dam site selection with social, economic and environmental considerations.

2 Methodology

In this paper, fuzzy TOPSIS MCDM (Chen 2000 and Chen and Hwang 1992) was used based on group decision-making considering experts' opinions in the form of a steering committee and converting their linguistic expressions into fuzzy triangular numbers according to specified criteria.

Triangular fuzzy sets are used in the transmission of the fuzzy concept of MCDM methods (Opricovic and Tzeng 2002). A triangular fuzzy number (TFN) (Eq. 1) is a fuzzy number that is shown by three points $\tilde{M} = \left(a_{ij}, b_{ij}, c_{ij}\right)$ (Kahraman et al. 2003).

where $a_{ij} \leq b_{ij} \leq c_{ij}$. The membership function of a triangular fuzzy number is as follows (Kahraman et al. 2003; Chen and Chen 2010):

$$\mu_M(x) = \begin{cases} \frac{x-a_{ij}}{b_{ij}-a_{ij}} & a_{ij} < x < b_{ij} \\ \frac{c_{ij}-x}{c_{ij}-b_{ij}} & b_{ij} < x < c_{ij} \\ 0 & \text{else} \end{cases} \tag{1}$$

where $\mu_M(x) \in [0, 1]$

The TFN $\tilde{M} = \left(a_{ij}, b_{ij}, c_{ij}\right)$ is represented in the geometric space as Fig. 1.

Mathematical operations on triangular fuzzy numbers are fulfilled according to Eqs. (2–7) as follows (Zimmermann 2001; Chen and Chen 2010):

$$\begin{cases} A_k = \tilde{M}_K & k = 1, \ldots k \\ A_k = \left(a_{ij_k}, b_{ij_k}, c_{ij_k}\right) & k = 1, \ldots, k \end{cases} \tag{2}$$

$$A_1 \oplus A_2 = \left(a_{ij_1} \oplus a_{ij_2}, b_{ij_1} \oplus b_{ij_2}, c_{ij_1} \oplus c_{ij_2}\right) \tag{3}$$

$$A_1 - A_2 = \left(a_{ij_1} - a_{ij_2}, b_{ij_1} - b_{ij_2}, c_{ij_1} - c_{{}_2}\right) \tag{4}$$

$$A_1 \otimes A_2 = \left(a_{ij_1} \otimes a_{ij_2}, b_{ij_1} \otimes b_{ij_2}, c_{ij_1} \otimes c_{ij_2}\right) \tag{5}$$

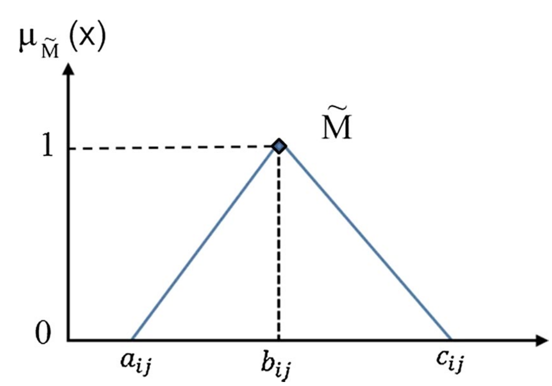

Fig. 1 Geometric space of the membership function of used TFN (reproduced with the permission from Kahraman et al. 2003)

$$\frac{A_1}{A_2} = \left(\frac{a_{ij_1}}{c_{ij_2}}, \frac{b_{ij_1}}{b_{ij_2}}, \frac{c_{ij_1}}{a_{ij_2}}\right) \quad (6)$$

$$A_1^{-1} = \left(\frac{1}{c_{ij_1}}, \frac{1}{b_{ij_1}}, \frac{1}{a_{ij_1}}\right) \quad (7)$$

Following that, general steps of fuzzy TOPSIS method can be summed up in the present approach as follows:

Step 1 Formation of the decision-making committee:

First, a committee of relevant experts should be formed to identify and evaluate the criteria and alternatives offered.

Step 2 Determination of fuzzy scales for converting the linguistic variables to fuzzy numbers (Table 1):

We need to define fuzzy scales to express the importance of decision components (criteria and alternatives) and the conversion of linguistic variables to TFNs, which these scales may be differed depending on the viewpoint of the decision-making committee and the type of problem.

Figure 2 manifests the way of converting linguistic variables to fuzzy scales through TFN.

Step 3 Getting experts' opinion about the importance of decision components:

At this stage, the advice of the experts is taken on the significance of the criteria and the importance of alternatives about each criterion in the form of a questionnaire.

Step 4 The combination of the experts' opinion and formation of the fuzzy matrix of criteria weight:

If there is a MCDM problem consisting of n criteria and m alternatives, the fuzzy decision matrix of the problem will be $\tilde{D} = [\tilde{M}]_{m*n}$.

where decision-making committee has k decision makers, $\tilde{M} = (a_{ij}, b_{ij}, c_{ij})$ is a combined fuzzy number of performance of the alternative ith ($i = 1, 2, \ldots, m$) in relation to criterion jth ($j = 1, 2, \ldots, n$).

If decision-making committee has k decision makers:$\tilde{M}_K = (a_{ijk}, b_{ijk}, c_{ijk})$. The combined fuzzy number of the performance of the alternative i on the criterion Ci can be obtained from Eqs. (8–11) as follows (Chen and Hwang 1992):

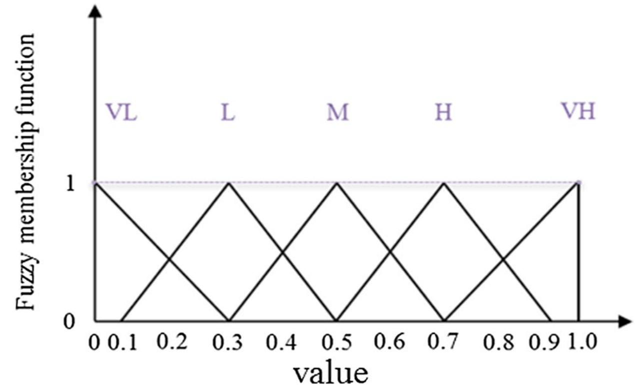

Fig. 2 Fuzzy triangular scale

$$\tilde{M} = (a_{ij}, b_{ij}, c_{ij}) \quad (8)$$

$$a_{ij} = \min_k \{a_{ijk}\} \quad k = 1, \ldots, k \quad (9)$$

$$b_{ij} = \left(\sum_{k=1}^{k} b_{ijk}\right)^{1/k} \quad k = 1, \ldots, k \quad (10)$$

$$c_{ij} = \max_k \{c_{ijk}\} \quad k = 1, \ldots, k \quad (11)$$

where $a_{ij} < b_{ij} < c_{ij}$,c_{ijk} denotes the importance of alternative i concerning criterion j based on the viewpoint of expert k; i, j and k are the number of alternatives, the number of criteria and the number of experts involved in the decision making, respectively.

Step 5 Normalizing the fuzzy decision matrix:

In this step, the entries of the fuzzy decision matrix are normalized using Eqs. (12–13) (Chen 2000):

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_{ij}^*}, \frac{b_{ij}}{c_{ij}^*}, \frac{c_{ij}}{c_{ij}^*}\right) \quad c_{ij}^* = \max\{c_{ij}\} \quad \text{if} \quad j \in B \quad (12)$$

$$\tilde{r}_{ij} = \left(\frac{a_{ij}^-}{c_{ij}}, \frac{a_{ij}^-}{b_{ij}}, \frac{a_{ij}^-}{a_{ij}}\right) \quad a_{ij}^- = \min\{a_{ij}\} \; if \; j \in c \quad (13)$$

Table 1 Linguistic statements and fuzzy scales for alternatives and criteria

Linguistic statements for the criteria importance	Fuzzy scale for criteria importance	Linguistic statements for evaluating alternatives	Fuzzy scale for evaluating alternatives
Very low (VL)	(0, 0.1, 0.3)	Very bad (VB)	(0, 1, 3)
Low (L)	(0.1, 0.3, 0.5)	Bad (B)	(1, 3, 5)
Medium (M)	(0.3, 0.5, 0.7)	Medium (M)	(3, 5, 7)
High (H)	(0.5, 0.7, 0.9)	Good (G)	(5, 7, 9)
Very High (VH)	(0.7, 0.9, 1)	Very good (VG)	(7, 9, 10)

where B and C are the set of positive and negative criteria, respectively.

Therefore, the normalized fuzzy decision matrix is obtained as (Chen 2000):

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m*n} \quad i = 1, \dots, m \quad j = 1, \dots, n \tag{14}$$

Step 6 The combination of the experts' opinions and formation of the fuzzy matrix of criteria weight:

The importance weight of different criteria in decision making is defined as follows (Chen and Hwang 1992):

$$\tilde{W} = \left[\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n\right] \tag{15}$$

$$\tilde{W}_j = \left[\tilde{w}_{j1}, \tilde{w}_{j2}, \dots, \tilde{w}_{jn}\right] \tag{16}$$

In which $\tilde{w}_j$ is the TFN, expressing the fuzzy weight of criterion j.

If decision-making committee has k decision makers, Eqs. (17–20) can be defined as follows:

$$\tilde{W}_{jk} = \left[\tilde{w}_{jk1}, \tilde{w}_{jk2}, \dots, \tilde{w}_{jkn}\right] \tag{17}$$

$$\tilde{w}_{j1} = \min_k \left\{\tilde{w}_{jk1}\right\} \tag{18}$$

$$\tilde{w}_{j2} = \left(\sum_{k=1}^{k} \tilde{w}_{jk2}\right)^{1/k} \tag{19}$$

$$\tilde{w}_{j3} = \max_k \left\{\tilde{w}_{jk3}\right\} \tag{20}$$

In which $\tilde{w}_{jk}$ is the fuzzy weight of criterion j based on the Kth expert.

Step 7 Formation of the normalized-weighted fuzzy decision matrix:

With respect to the importance coefficient of various criteria, the normalized-weighted fuzzy decision matrix is obtained through multiplying the importance coefficient of each criterion in the fuzzy normalized matrix as follows:

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m*n} \tag{21}$$

$$\tilde{V}_{ij} = \tilde{v}_{ij} \,.\, \tilde{w}_j \tag{22}$$

where $\tilde{w}_j$ is the importance coefficient of criterion C_j.

Then $\tilde{v}_{ij}$ is obtained as:

$$\tilde{v}_{ij} = \left(\frac{a_{ij}}{c^*_{ij}} . \tilde{w}_{j1}, \frac{b_{ij}}{c^*_{ij}} . \tilde{w}_{j2}, \frac{c_{ij}}{c^*_{ij}} . \tilde{w}_{j3}\right) \tag{23}$$

$$\tilde{v}_{ij} = \left(\frac{a^-_{ij}}{c_{ij}} . \tilde{w}_{j1}, \frac{a^-_{ij}}{b_{ij}} . \tilde{w}_{j2}, \frac{a^-_{ij}}{a_{ij}} . \tilde{w}_{j3}\right) \tag{24}$$

where Eqs. (23–24) can be defined as the positive and negative aspects of the criteria, respectively.

Step 8 Finding FPIS $\left(\tilde{A}^*\right)$ and FNIS $\left(\tilde{A}^-\right)$ which can be obtained through Eqs. (25–28) (Chen and Hwang 1992):

$$\tilde{A}^* = \left\{\tilde{v}^*_1, \tilde{v}^*_2, \dots, \tilde{v}^*_n\right\} \tag{25}$$

$$\tilde{v}^*_J = \max_j \left\{\tilde{v}^*_{ij}\right\} \quad i = 1, \dots m \quad j = 1, \dots, n, \tag{26}$$

$$\tilde{A}^- = \left\{\tilde{v}^-_1, \tilde{v}^-_2, \dots, \tilde{v}^-_n\right\} \tag{27}$$

$$\tilde{v}^-_J = \min_i \left\{\tilde{v}^-_{ij}\right\} \quad i = 1, \dots m \quad j = 1, \dots, n, \tag{28}$$

where $\tilde{v}^*_j$ and $\tilde{v}^-_j$ are the best and worst values of criterion Jth among all alternatives, respectively.

Step 9 Distance calculation of each alternative from FPIS and FNIS:

$$S^*_i = \sum d_V \left(\tilde{v}_{ij}, \tilde{v}^*_J\right) \quad i = 1, \dots m \quad j = 1, \dots, n \tag{29}$$

$$S^-_i = \sum d_V \left(\tilde{v}_{ij}, \tilde{v}^-_J\right) \quad i = 1, \dots m \quad j = 1, \dots, n \tag{30}$$

$$d_V \left(\tilde{v}_{ij}, \tilde{v}^*_J\right) = \sqrt{\frac{1}{3}\left(\sum \left(\tilde{v}_{ij} - \tilde{v}^*_J\right)^2\right)} \tag{31}$$

$$d_V \left(\tilde{v}_{ij}, \tilde{v}^-_J\right) = \sqrt{\frac{1}{3}\left(\sum \left(\tilde{v}_{ij} - \tilde{v}^-_J\right)^2\right)} \tag{32}$$

Step 10 The calculation of the closeness coefficient C_i:

The calculation of the closeness coefficient C_i is obtained from the following equation:

$$C_i = \frac{S^-_i}{S^*_i + S^-_i} \quad i = 1, \dots m \tag{33}$$

Step 11 Alternatives ranking:

In this step, alternatives are prioritized according to the value of closeness coefficient so that the alternatives with higher closeness coefficient are in preference.

3 Case study: problem definition and issue importance

The studied area is located in the west of Iran and within Kermanshah and Sahneh counties. The studied area is surrounded by Karambast, Kandoleh and Darab villages. This area includes four sub-basins. The main river of sub-basins of alternatives 1 and 4 discharges into the Dinoorab River by passing from Mian Rahan plain, and also, the main river of alternatives 2 and 3 discharges into the Razavar River by passing from Kamiaran plain, where both of them enter the Gharesoo River. The alternative of site 1 is located in the upstream side of Karambast, Pariyan, Sharifabad and Kandoleh, and alternatives 2–3 are among Boulan, Jezr, Darab and Saranjge. Alternative 4 is in upstream of Pariyan, Sharifabad and Kandoleh (see Fig. 3).

With respect to the limited resources of freshwater and renewable water and the increase in the use of optimal and sustainable utilization of existing water resources, water resources management has always gotten water industry policy-makers attention. Kermanshah province is not the exception so that in last years the studies have been begun about a reservoir dam within Kermanshah and Sahneh (Minatour et al. 2013, 2015a, b). Regarding the growing population and an increase in urban water demand resulting in a decrease in accessibility to water, supplying the water needs of the area will be a considerable challenge (Niemczynowicz 1999). Hence, the construction of the Kandoleh reservoir dam in an optimal site is one of the solutions to meet the needs of irrigation of agricultural lands and urban needs and will bring economic prosperity to the region. Accordingly, selecting an appropriate site for this dam has been studied to achieve possible results by applying the proposed decision-making model.

3.1 Criteria for selecting dam site

With respect to different conditions of the area including being extensive of the case studied, topographic, environmental and hydrology features, as well as other water resource-related issues, a wide variety of criteria, were

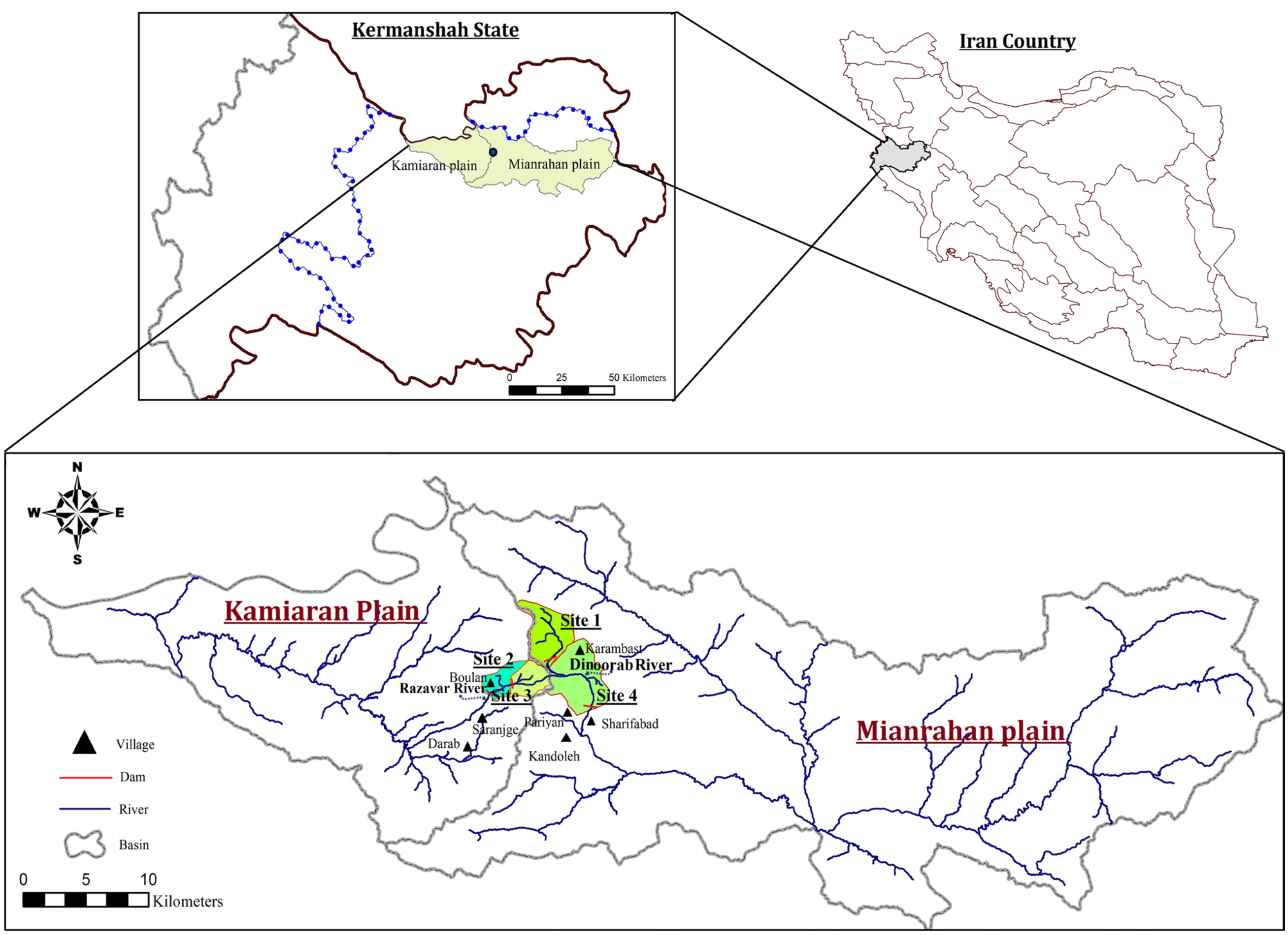

Fig. 3 Location of the studied area and alternatives proposed

evaluated by aforementioned experts. Added to this, extensive library studies were done to help the criteria selection. Table 2 shows the effective criteria for choosing a dam site and its positive and negative aspects.

Brief explanations of the criteria related to Table 2 are presented as follows.

3.1.1 The safety of the site and reservoir

Dam site should be selected where the seams and cracks and the possibility of tectonic activities such as earthquake and landslide are low, and the sustainability of the supports is high. Besides, the geological layers of the area should be considered concerning the impact on the reservoir water quality, the construction of the foundation and the reservoir and stability in the case of rapid discharge.

3.1.2 Total cost

The general cost of constructing a dam is another important criterion in selecting a dam site. These costs include the costs of construction of the body and the reservoir of a dam, the cost of water diversion, the transmission of water after the construction, building and preparation workshop, wages, supply of materials and other expenses associated with dam construction projects.

Table 2 Effective criteria for selecting dam site

criterion	Definition	Positive or negative aspect
C1	The safety of the site and reservoir	Positive
C2	Total cost	Negative
C3	Hydrologic criterion	Positive
C4	Topographic conditions of the location	Positive
C5	Accessibility to materials and facilities	Positive
C6	Economic development	Positive
C7	Water resource quality	Positive
C8	Reservoir and body damages	Negative
C9	Reservoir capacity	Positive
C10	River flow regime	Positive
C11	Transmission and water diversion	Negative
C12	The annual volume of the reservoir sediment	Negative
C13	The possibility of constructing workshop	Positive
C14	The probable maximum flood	Negative
C15	Weather condition	Negative
C16	Environmental effects	Positive
C17	Social acceptability	Positive
C18	Political effects	Positive

3.1.3 Hydrologic criterion

It indicates the annual discharge and inputs of the river in dam site and precipitation amount over the upstream basin.

3.1.4 Topographic conditions of the place

Of the most practical criteria affecting the location of dam site is the topographic condition in which, for instance, the existence of rock bases with appropriate topography and U or S shape of the main river can affect the construction place.

3.1.5 Accessibility to materials and facilities

The easier access to resources can help the construction cost and time to decrease.

3.1.6 Economic development

The principal effects which dam construction can bring to the location of a dam site are agriculture development, power production, creating jobs, industrial development.

3.1.7 Reservoir water quality management

The water quality stored in a reservoir is important regarding drinking and agricultural uses. Furthermore, the percentage of water quality is different for different purposes; therefore, dam site should be selected in a place to cover all quality requirements.

3.1.8 The damages stemming from body and reservoir of the dam

The amount of caused damages should be considered regarding the environment, agricultural lands, residential area due to the dam construction.

3.1.9 Dam reservoir capacity

The larger capacity of the constructed reservoir causes more influence on the region's weather due to the increased water surface of the reservoir.

3.1.10 River flow regime

Being seasonal or permanent of the river flow regime is important to select dam site. Sediment transportation and water quality are high and low, respectively, in seasonal rivers. Therefore, it would be better for rivers to reach the permanent condition

3.1.11 Transmission and water diversion

Dam site should be selected where the water diversion cost can be decreased during construction and water transmission.

3.1.12 The annual volume of the entering sediment to the reservoir

The lower entering sediment to the reservoir gets the useful volume of the reservoir and water quality to be more. Furthermore, the less entering sediment to the reservoir makes the expenditure of sediment evacuation lessened. Generally, higher efficiency of a dam would be obtained by less entering sediment.

3.1.13 The possibility of constructing workshop

It would be better to build the workshop close to the dam site to decrease the possible costs.

3.1.14 The probable maximum flood

The maximum flow discharge (flood) will occur in snow and ice melting or possible precipitation. It would be better to have the less likely maximum flood.

3.1.15 Weather condition

Cloudy and rainy weather and temperature decrease prevent the work progresses. With respect to the differences of annual mean temperature among different regions of Iran, the amount of evaporation from the reservoir surface is different affecting the precipitation time in the reservoir.

3.1.16 Environmental effects

Climate change, vegetation and wildlife are among the other important criteria for choosing a dam site.

3.1.17 Social effects

The displacement of the population centers and the combination of different ethnic cultures should be considered due to the destruction of the residential areas in order to dam construction or other related issues.

3.1.18 Political effects

Reducing political tensions is another prominent factor regarding providing the water required for a city, preventing dissatisfaction and migration of residents.

3.2 Alternatives

In this paper, four suggested alternatives were investigated using fuzzy TOPSIS group decision-making model based on hydraulic, hydrology, meteorology and environmental reports conducted by Consultant Company. Thereafter, an appropriate site was introduced for constructing the dam.

3.3 Applying the proposed method

The first step, four dam experts participating in the project were questioned using linguistic expressions contained in the questionnaire in order to calculate the criteria importance and evaluation of the alternatives in relation to the criteria (see Tables 3–4). In the second step, the opinions of four experts were received about the importance weight of criteria and rating of alternatives based on each criterion by handing out one questionnaire to each of them; then, received opinions were converted to TFNs by using fuzzy scales presented in Table 1 (see "Appendices 1 and 2"). In the next stage, fuzzy decision matrix of the problem was formed by the combination of the fuzzy numbers of experts' opinions that have been obtained using Eqs. (8–11) (see Table 5).

In all Tables, D1–D4 and 1–4 are experts and alternatives, respectively.

The normalized decision matrix of the problem was achieved using Table 5. The results are presented in Table 6.

In the next step, the fuzzy matrix of criteria weight was formed by the combination of the fuzzy numbers of experts' opinions given in Table 3. The results are presented in Table 7. According to the importance coefficient of different criteria, weighted fuzzy decision matrix (Table 8) was obtained by multiplying the normalized fuzzy decision matrix (Table 6) and a fuzzy matrix of criteria weight (Table 7); in the next stage, FPIS and FNIS were measured using Eqs. (26) and (28), respectively, based on each criterion; then, FPIS and FNIS were also obtained using Eqs. (25) and (27), respectively (see Table 9).

Furthermore, FPIS and FNIS were calculated using Eqs. (25) and (27), respectively, as follows:

$\tilde{A}^* = \{(1,1,1),(0.9,0.9,0.9),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(0.9,0.9,0.9),(0.9,0.9,0.9),(0.9,0.9,0.9), (1,1,1),(0.9,0.9,0.9),(1,1,1),(0.9,0.9,0.9),(0.9,0.9,0.9),(0.9,0.9,0.9),(0.7,0.7,0.7),(0.5,0.5,0.5)\}$.

$\tilde{A}^- = \{(0.07,0.07,0.07),(0.011,0.011,0.011),(0.05,0.05,0.05),(0.03,0.03,0.03),(0.07,0.07,0.07), (0.2,0.2,0.2),(0.05,0.05,0.05),(0.03,0.03,0.03),(0.03,0.03,0.03),(0.033,0.033,0.033),(0.05,0.05,0.05), (0.01,0.01,0.01),(0.05,0.05,0.05),(0.01,0.01,0.01),(0.033,0.033,0.033),(0.01,0.01,0.01),(0.03,0.03,0.03), (0.014, 0.014, 0.014)\}$.

The FPIS and FNIS of each alternative were calculated using Eqs. (29) and (30), respectively. For this purpose, first,

Table 3 Experts' opinion about criteria importance

Criteria	Definition	Decision makers			
		D1	D2	D3	D4
C1	The safety of the site and reservoir	VH	VH	VH	VH
C2	Total cost	M	L	H	H
C3	Hydrologic criterion	VH	H	VH	H
C4	Topographic conditions of the location	H	VH	H	M
C5	Accessibility to materials and facilities	VH	VH	VH	VH
C6	Economic development	VH	VH	VH	H
C7	Water resource quality	H	H	VH	VH
C8	Reservoir and body damages	H	H	M	H
C9	Reservoir capacity	L	H	H	M
C10	River flow regime	H	M	L	L
C11	Transmission and water diversion	VH	H	VH	VH
C12	The annual volume of the reservoir sediment	M	M	H	H
C13	The possibility of constructing workshop	VH	H	VH	VH
C14	The probable maximum flood	H	H	L	M
C15	Weather condition	M	K	L	H
C16	Environmental effects	M	M	H	L
C17	Social acceptability	M	M	L	L
C18	Political effects	L	L	L	L

the distance of each alternative from FPIS and FNIS of each criterion was obtained using Eqs. (31) and (32), respectively. The distance of the alternatives from FPIS and FNIS of each criterion is shown in Table 10.

For instance, the following values of FPIS and FNIS can be obtained through Eqs. (29–30) for alternative 1:

$$S_1^* = \{0.65 + 0.51 + 0.58 + 0.48 + 0.53 + 0.76 + 0.59 + 0.40 + 0.66 + 0.55 + 0.38 + 0.52 + 0.60 + 0.48 + 0.53 + 0.54 + 0.71 + 1.00\} = 10.47$$

$$S_1^- = \{0.58 + 0.63 + 0.60 + 0.63 + 0.63 + 0.61 + 0.59 + 5.36 + 0.59 + 0.63 + 3.65 + 1.00 + 0.58 + 0.64 + 0.64 + 0.68 + 0.91 + 1.10\} = 20.06$$

For instance, the distance of the FPIS and FNIS of criterion C1 and alternative 1 has been achieved using Eqs. (31–32).

$$d_V\left(\tilde{v}_{11}, \tilde{v}_1^*\right) = \sqrt{\frac{1}{3}\left((0.21-1)^2 + (0.6-1)^2 + (0.9-1)^2\right)} = 0.65$$

$$d_V\left(\tilde{v}_{11}, \tilde{v}_1^-\right) = \sqrt{\frac{1}{3}\left((0.21-0.07)^2 + (0.6-0.07)^2 + (0.9-0.07)^2\right)} = 0.58$$

In the last step, the closeness coefficient is measured for each alternative using Eq. (33) as shown below:

$$C_1 = \frac{20.06}{10.47 + 20.06} = 0.657$$

$$C_2 = \frac{16.33}{10.26 + 16.33} = 0.614$$

$$C_3 = \frac{15.84}{10.54 + 15.84} = 0.600$$

$$C_4 = \frac{11.42}{11.35 + 11.42} = 0.501$$

In Table 11, the alternatives ranking is shown based on FPIS and FNIS of each alternative and closeness coefficients.

As can be seen, the closeness coefficient of alternative 1 is greater than the others, and the alternative 1 was introduced as the optimum site for Kandoleh reservoir dam.

4 Analysis of the obtained results

The significant difference in the utilized method with other MCDM methods is that the ranking results and criteria weight can be precisely investigated. Therefore, the employed method has been able to consider various criteria including economic, technical, environmental and social in evaluating and alternatives ranking.

The effect of each criterion on alternatives was different. As given in Table 10, for example, while total cost criterion had the most significant effect on alternative 2, transmission

Table 4 Experts' opinion about evaluation of alternatives in relation to the criteria

Criteria	Decision makers	Alternatives			
		1	2	3	4
C1$^{(+)}$	D1	G	G	VG	VG
	D2	G	M	G	VG
	D3	M	B	G	VG
	D4	G	G	VG	G
C2$^{(-)}$	D1	G	VG	VG	G
	D2	M	G	G	M
	D3	G	VG	M	B
	D4	B	G	M	B
C3$^{(+)}$	D1	G	G	G	VG
	D2	G	B	G	G
	D3	M	B	M	G
	D4	M	G	G	VG
C4$^{(+)}$	D1	B	G	G	VG
	D2	B	M	G	G
	D3	M	VG	M	VG
	D4	G	G	B	G
C5$^{(+)}$	D1	G	VG	G	G
	D2	M	G	G	G
	D3	B	G	M	M
	D4	M	VG	G	G
C6$^{(+)}$	D1	G	G	G	G
	D2	G	M	M	M
	D3	G	G	G	G
	D4	G	G	G	G
C7$^{(+)}$	D1	G	G	G	VG
	D2	G	M	G	G
	D3	M	B	M	G
	D4	G	G	B	VG
C8$^{(-)}$	D1	VG	G	G	B
	D2	VG	G	M	B
	D3	VG	VG	G	M
	D4	VG	VG	G	M
C9$^{(+)}$	D1	VG	G	G	VG
	D2	G	M	M	VG
	D3	G	B	M	VG
	D4	VG	G	G	G
C10$^{(+)}$	D1	G	G	G	G
	D2	M	M	M	M
	D3	M	M	M	M
	D4	G	G	G	G
C11$^{(-)}$	D1	VG	G	G	B
	D2	VG	G	G	B
	D3	G	M	M	B
	D4	VG	G	G	M
C12$^{(-)}$	D1	G	G	M	M
	D2	G	G	M	G
	D3	VG	VG	M	M
	D4	VG	G	M	M

Table 4 (continued)

Criteria	Decision makers	Alternatives			
		1	2	3	4
C13$^{(+)}$	D1	G	VG	G	G
	D2	G	VG	G	M
	D3	M	G	M	M
	D4	G	G	G	B
C14$^{(-)}$	D1	G	VG	G	B
	D2	M	M	M	M
	D3	B	B	B	B
	D4	G	G	G	B
C15$^{(-)}$	D1	M	M	M	M
	D2	M	M	M	M
	D3	G	G	G	G
	D4	G	G	G	G
C16$^{(+)}$	D1	G	M	G	G
	D2	G	M	G	VG
	D3	M	M	M	M
	D4	M	B	B	G
C17$^{(+)}$	D1	M	M	G	M
	D2	M	G	G	G
	D3	G	G	G	G
	D4	G	VG	VG	G
C18$^{(+)}$	D1	M	M	M	M
	D2	B	B	B	B
	D3	B	B	B	B
	D4	M	M	M	M

Table 5 Fuzzy decision matrix of dam site selection obtained by Eqs. (8–11)

Criteria	Alternatives			
	1	2	3	4
C1$^{(+)}$	(3, 6.5, 9)	(1, 5.5, 9)	(5, 8, 10)	(5, 8.5, 10)
C2$^{(-)}$	(1, 5.5, 9)	(5, 8, 10)	(3, 6.5, 10)	(1,, 4.5, 9)
C3$^{(+)}$	(3, 6, 9)	(1, 5, 9)	(3, 6.5, 9)	(5, 8, 10)
C4$^{(+)}$	(1, 4.5, 9)	(3, 7, 10)	(1, 5.5, 9)	(5, 8.5, 10)
C5$^{(+)}$	(1, 5, 9)	(5, 8, 10)	(1, 6.25, 9)	(3, 6.5, 9)
C6$^{(+)}$	(5, 7, 9)	(3, 6.5, 9)	(3, 6.5, 9)	(3, 6.5, 9)
C7$^{(+)}$	(3, 6.5, 9)	(1, 5.5, 9)	(1, 5.5, 9)	(5, 8, 10)
C8$^{(-)}$	(7, 9, 10)	(5, 8, 10)	(3, 6.5, 9)	(1, 4, 7)
C9$^{(+)}$	(5, 8, 10)	(1, 5.5, 9)	(3, 6, 9)	(5, 8.5, 10)
C10$^{(+)}$	(3, 6, 9)	(3, 6, 9)	(3, 6, 9)	(3, 6, 9)
C11$^{(-)}$	(5, 8.5, 10)	(3, 6.5, 9)	(3, 6.5, 9)	(1, 3.5, 7)
C12$^{(-)}$	(5, 8, 10)	(5, 8, 10)	(3, 5, 7)	(3, 5.5, 9)
C13$^{(+)}$	(3, 6.5, 9)	(5, 8, 10)	(3, 6.5, 9)	(1, 5, 9)
C14$^{(-)}$	(1, 5.5, 9)	(1, 6, 10)	(1, 5.5, 9)	(1, 3.5, 7)
C15$^{(-)}$	(3, 6, 9)	(3, 6, 9)	(3, 6, 9)	(3, 6, 9)
C16$^{(+)}$	(3, 6, 9)	(1, 4.5, 7)	(1, 5.5, 9)	(3, 7, 10)
C17$^{(+)}$	(3, 6, 9)	(3, 7, 10)	(5, 7.5, 10)	(3, 6.5, 9)
C18$^{(+)}$	(1, 4, 7)	(1, 4, 7)	(1, 4, 7)	(1, 4, 7)

Table 6 Normalized fuzzy decision matrix of dam site selection using Eqs. (12–14)

Criteria	Alternatives			
	1	2	3	4
C1$^{(+)}$	(0.3, 0.65, 0.9)	(0.1, 0.55, 0.9)	(0.5, 0.8, 1)	(0.5, 0.85, 1)
C2$^{(-)}$	(0.11, 0.18, 1)	(0.1, 0.125, 0.2)	(0.1, 0.15, 0.33)	(0.11, 0.22, 1)
C3$^{(+)}$	(0.3, 0.6, 0.9)	(0.1, 0.5, 0.9)	(0.3, 0.65, 0.9)	(0.5, 0.8, 1)
C4$^{(+)}$	(0.1, 0.45, 0.9)	(0.3, 0.7, 1)	(0.1, 0.55, 0.9)	(0.5, 0.85, 1)
C5$^{(+)}$	(0.1, 0.5, 0.9)	(0.5, 0.8, 1)	(0.1, 0.625, 0.9)	(0.3, 0.65, 0.9)
C6$^{(+)}$	(0.55, 0.78, 1)	(0.33, 0.72, 1)	(0.33, 0.72, 1)	(0.33, 0.72, 1)
C7$^{(+)}$	(0.3, 0.65, 0.9)	(0.1, 0.55, 0.9)	(0.1, 0.55, 0.9)	(0.5, 0.8, 1)
C8$^{(-)}$	(0.1, 0.11, 0.143)	(0.1, 0.125, 0.2)	(0.11, 0.154, 0.33)	(0.143, 0.25, 1)
C9$^{(+)}$	(0.5, 0.8, 1)	(0.1, 0.55, 0.9)	(0.3, 0.6, 0.9)	(0.5, 0.85, 1)
C10$^{(+)}$	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)
C11$^{(-)}$	(0.1, 0.12, 0.2)	(0.11, 0.154, 0.33)	(0.11, 0.154, 0.33)	(0.143, 0.28, 1)
C12$^{(-)}$	(0.3, 0.375, 0.6)	(0.3, 0.33, 0.6)	(0.428, 0.6, 1)	(0.33, 545, 1)
C13$^{(+)}$	(0.3, 0.65, 0.9)	(0.5, 0.8, 1)	(0.3, 0.65, 0.9)	(0.1, 0.5, 0.9)
C14$^{(-)}$	(0.11, 0.181, 1)	(0.1, 0.166, 1)	(0.11, 0.181, 1)	(0.412, 0.285, 1)
C15$^{(-)}$	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(0.33, 0.5, 1)
C16$^{(+)}$	(0.3, 0.6, 0.9)	(0.1, 0.45, 0.7)	(0.1, 0.55, 0.9)	(0.3, 0.7, 1)
C17$^{(+)}$	(0.3, 0.6, 0.9)	(0.3, 0.7, 1)	(0.5, 0.75, 1)	(0.3, 0.65, 0.9)
C18$^{(+)}$	(0.143, 0.57, 1)	(0.14, 0.57, 1)	(0.14, 0.57, 1)	(0.14, 0.57, 1)

and water diversion criterion played the most significant influence on alternative 1 to obtain the FPIS (see Table 10 and Fig. 4A). Likewise, based on Table 10 and Fig. 4B, the possibility of constructing workshop and the safety of the site and reservoir criteria have the minimum effect on alternative 1 due to the minim distance from FNIS.

Table 7 Fuzzy matrix of criteria weight obtained by Eqs. (15–20)

Criteria	Combined fuzzy weight
C1$^{(+)}$	(0.7, 0.9, 1)
C2$^{(-)}$	(0.1, 0.55, 0.9)
C3$^{(+)}$	(0.5, 0.8, 1)
C4$^{(+)}$	(0.3, 0.7, 1)
C5$^{(+)}$	(0.7, 0.9, 1)
C6$^{(+)}$	(0.5, 0.85, 1)
C7$^{(+)}$	(0.5, 0.8, 1)
C8$^{(-)}$	(0.3, 0.65, 0.9)
C9$^{(+)}$	(0.3, 0.55, 0.9)
C10$^{(+)}$	(0.1, 0.45, 0.9)
C11$^{(-)}$	(0.5, 0.85, 1)
C12$^{(-)}$	(0.3, 0.6, 0.9)
C13$^{(+)}$	(0.5, 0.85, 1)
C14$^{(-)}$	(0.1, 0.55, 0.9)
C15$^{(-)}$	(0.1, 0.5, 0.9)
C16$^{(+)}$	(0.1, 0.5, 0.9)
C17$^{(+)}$	(0.1, 0.4, 0.7)
C18$^{(+)}$	(0.1, 0.3, 0.5)

Generally, by considering all criteria, alternative 1 by the value of 18.42 has the farthest distance from FNIS. Since selected alternative should have the highest closeness coefficient among alternatives, the minimum and maximum distance from FPIS and FNIS, alternative 1 is considered as the first rank (see Table 11 and Fig. 5). On the other hand, other alternatives had lower closeness coefficient in relation to alternative 1 and descended to lower ranks due to the lack of the simultaneous the closest and farthest distance from FPIS and FNIS.

A sensitivity analysis was also done for alternatives ranking based on the importance of criteria weight in fuzzy TOPSIS method by calculating the distance from FPIS and FNIS and closeness coefficient. In following, the way of ranking without considering the importance of criteria in relation to final ranking was fulfilled, and following results were obtained:

If the importance of criteria weight including C3, C7, C9, C10, C14 and C15 decreases or the effect of them is not considered in the final ranking, alternative ranking in relation to final ranking will not change. In fact, these criteria play the lowest impact on choosing an ideal alternative (Fig. 6).

By investigating closeness coefficient and distance from FPIS and FNIS in the ranking without considering C6, C8 and C11, it was specified that these values changed in all alternatives that this changes alternative ranking compared

Table 8 Weighted fuzzy decision matrix of dam site selection Eqs. (21–24)

Criteria	Alternatives			
	1	2	3	4
$C1^{(+)}$	(0.21, 0.6, 0.9)	(0.07, 0.5, 0.9)	(0.32, 0.72, 1)	(0.35, 0.8, 1)
$C2^{(-)}$	(0.011, 0.2, 0.9)	(0.01, 0.07, 0.18)	(0.01, 0.08, 0.3)	(0.011, 0.121, 0.9)
$C3^{(+)}$	(0.15, 0.5, 0.9)	(0.05, 0.4, 0.9)	(0.15, 0.52, 0.9)	(0.25, 0.64, 1)
$C4^{(+)}$	(0.03, 0.315, 0.9)	(0.09, 0.5, 1)	(0.03, 0.4, 0.9)	(0.15, 0.6, 1)
$C5^{(+)}$	(0.07, 0.45, 0.9)	(0.21, 0.72, 1)	(0.07, 0.6, 0.9)	(0.35, 0.6, 0.9)
$C6^{(+)}$	(0.3, 0.7, 1)	(0.2, 0.6, 1)	(0.2, 0.6, 1)	(0.2, 0.6, 1)
$C7^{(+)}$	(0.15, 0.52, 0.9)	(0.05, 0.44, 0.9)	(0.05, 0.44, 0.9)	(0.25, 0.64, 1)
$C8^{(-)}$	(0.1, 0.11, 0.143)	(0.1, 0.125, 0.2)	(0.33, 0.1, 0.3)	(0.043, 0.2, 0.9)
$C9^{(+)}$	(0.15, 0.44, 0.9)	(0.03, 0.3, 0.81)	(0.09, 0.33, 0.81)	(0.15, 0.5, 0.9)
$C10^{(+)}$	(0.033, 0.3, 0.9)	(0.033, 0.3, 0.9)	(0.033, 0.3, 0.9)	(0.033, 0.3, 0.9)
$C11^{(-)}$	(0.05, 0.1, 0.2)	(0.055, 0.13, 0.33)	(0.055, 0.13, 0.33)	(0.071, 0.24, 1)
$C12^{(-)}$	(0.09, 0.225, 0.54)	(0.09, 0.225, 0.54)	(0.13, 0.36, 0.9)	(0.01, 33, 0.9)
$C13^{(+)}$	(0.15, 0.552, 0.9)	(0.25, 0.7, 1)	(0.15, 0.552, 0.9)	(0.05, 0.425, 0.9)
$C14^{(-)}$	(0.011, 0.1, 0.9)	(0.01, 0.1, 0.9)	(0.011, 0.1, 0.9)	(0.014, 0.16, 0.9)
$C15^{(-)}$	(0.033, 0.25, 0.9)	(0.033, 0.25, 0.9)	(0.033, 0.25, 0.9)	(0.033, 0.25, 0.9)
$C16^{(+)}$	(0.03, 0.3, 0.81)	(0.01, 0.225, 0.63)	(0.01, 0.3, 0.819)	(0.03, 0.35, 0.9)
$C17^{(+)}$	(0.03, 0.24, 0.63)	(0.03, 0.3, 0.7)	(0.05, 0.3, 0.7)	(0.03, 0.3, 0.63)
$C18^{(+)}$	(0.014, 0.18, 0.5)	(0.014, 0.18, 0.5)	(0.014, 0.18, 0.5)	(0.014, 0.18, 0.5)

Table 9 FPIS and FNIS based on each criterion obtained by Eqs. (26) and (28)

Criteria	FPIS		FNIS	
	$\widetilde{V}_J^*$	Values	$\widetilde{V}_J^-$	Values
$C1^{(+)}$	$\widetilde{V}_1^*$	(1.0, 1.0, 1.0)	$\widetilde{V}_1^-$	(0.07, 0.07, 0.07)
$C2^{(-)}$	$\widetilde{V}_2^*$	(0.9, 0.9, 0.9)	$\widetilde{V}_2^-$	(0.011, 0.011, 0.011)
$C3^{(+)}$	$\widetilde{V}_3^*$	(1.0, 1.0, 1.0)	$\widetilde{V}_3^-$	(0.05, 0.05, 0.05)
$C4^{(+)}$	$\widetilde{V}_4^*$	(1.0, 1.0, 1.0)	$\widetilde{V}_4^-$	(0.03, 0.03, 0.03)
$C5^{(+)}$	$\widetilde{V}_5^*$	(1.0, 1.0, 1.0)	$\widetilde{V}_5^-$	(0.07, 0.07, 0.07)
$C6^{(+)}$	$\widetilde{V}_6^*$	(1.0, 1.0, 1.0)	$\widetilde{V}_6^-$	(0.2, 0.2, 0.2)
$C7^{(+)}$	$\widetilde{V}_7^*$	(1.0, 1.0, 1.0)	$\widetilde{V}_7^-$	(0.05, 0.05, 0.05)
$C8^{(-)}$	$\widetilde{V}_8^*$	(0.9, 0.9, 0.9)	$\widetilde{V}_8^-$	(0.03, 0.03, 0.03)
$C9^{(+)}$	$\widetilde{V}_9^*$	(0.9, 0.9, 0.9)	$\widetilde{V}_9^-$	(0.03, 0.03, 0.03)
$C10^{(+)}$	$\widetilde{V}_{10}^*$	(0.9, 0.9, 0.9)	$\widetilde{V}_{10}^-$	(0.033, 0.033, 0.033)
$C11^{(-)}$	$\widetilde{V}_{11}^*$	(1.0, 1.0, 1.0)	$\widetilde{V}_{11}^-$	(0.05, 0.05, 0.05)
$C12^{(-)}$	$\widetilde{V}_{12}^*$	(0.9, 0.9, 0.9)	$\widetilde{V}_{12}^-$	(0.01, 0.01, 0.01)
$C13^{(+)}$	$\widetilde{V}_{13}^*$	(1.0, 1.0, 1.0)	$\widetilde{V}_{13}^-$	(0.05, 0.05, 0.05)
$C14^{(-)}$	$\widetilde{V}_{14}^*$	(0.9, 0.9, 0.9)	$\widetilde{V}_{14}^-$	(0.01, 0.01, 0.01)
$C15^{(-)}$	$\widetilde{V}_{15}^*$	(0.9, 0.9, 0.9)	$\widetilde{V}_{15}^-$	(0.033, 0.033, 0.033)
$C16^{(+)}$	$\widetilde{V}_{16}^*$	(0.9, 0.9, 0.9)	$\widetilde{V}_{16}^-$	(0.01, 0.01, 0.01)
$C17^{(+)}$	$\widetilde{V}_{17}^*$	(0.7, 0.7, 0.7)	$\widetilde{V}_{17}^-$	(0.03, 0.03, 0.03)
$C18^{(+)}$	$\widetilde{V}_{18}^*$	(0.5, 0.5, 0.5)	$\widetilde{V}_{18}^-$	(0.014, 0.014, 0.014)

with a final ranking. Hence, C8, C6 and C11 criteria play the most impact on final ranking, respectively (Figs. 7, 8, 9).

Other criteria have a much lower impact than these three criteria, but without considering them the alternatives ranking changes in relation to final ranking. Therefore, to improve the precision, it appears these criteria to be considered. Table 12 shows the alternatives ranking when the importance of criteria weight is not considered.

Also, by doing analysis and comparing results, some unexpected issues were seen about the importance of criteria. Some criteria had more important than others in view of experts; in the employed method, other criteria were placed in the higher level of importance. As given in Table 3, for instance, all decision-making experts considered C1 and C5 criteria as the most important one, while fulfilled analysis specified that the importance of C8, C11 and C6 criteria is higher.

5 Discussion

The ELECTRE III is a non-compensatory multi-criteria decision-making model working based on outranking relations where comparisons are fulfilled by binary relations, and the importance of the criteria is specified as a number between 1 and 20 (Rogers and Bruen 1998; Figueira et al. 2005). While the SAW method is one of the simple multi-criteria decision-making models in which a weighted sum

Table 10 Alternatives distance from FPIS and FNIS obtained by Eqs. (29–32)

Criteria	Alternatives							
	1		2		3		4	
	Distance		Distance		Distance		Distance	
	FPIS	FNIS	FPIS	FNIS	FPIS	FNIS	FPIS	FNIS
$C1^{(+)}$	0.65	0.58	0.54	0.62	0.81	0.49	0.85	0.47
$C2^{(-)}$	0.51	0.63	0.41	3.2	0.43	1.93	0.49	0.64
$C3^{(+)}$	0.58	0.6	0.51	0.63	0.58	0.6	0.69	0.51
$C4^{(+)}$	0.48	0.63	0.56	0.53	0.5	0.61	0.61	0.51
$C5^{(+)}$	0.53	0.63	0.69	0.50	0.57	0.59	0.75	0.58
$C6^{(+)}$	0.76	0.61	0.64	0.64	0.64	0.64	0.64	0.64
$C7^{(+)}$	0.59	0.59	0.52	0.62	0.52	0.66	0.69	0.51
$C8^{(-)}$	0.4	3.72	0.42	1.72	0.44	1.4	0.52	0.59
$C9^{(+)}$	0.66	0.59	0.54	0.7	0.58	0.69	0.68	0.58
$C10^{(+)}$	0.55	0.63	0.55	0.63	0.55	0.63	0.55	0.63
$C11^{(-)}$	0.8	3.65	0.4	1.98	0.4	1.98	0.48	0.6
$C12^{(-)}$	0.52	1	0.52	1	0.61	0.6	0.55	0.61
$C13^{(+)}$	0.60	0.58	0.71	0.49	0.60	0.58	0.52	0.63
$C14^{(-)}$	0.48	0.64	0.48	0.64	0.48	0.64	0.5	0.64
$C15^{(-)}$	0.53	0.64	0.53	0.64	0.53	0.64	0.53	0.64
$C16^{(+)}$	0.54	0.68	0.50	0.88	0.54	0.68	0.56	0.6
$C17^{(+)}$	0.71	0.91	0.74	0.8	0.76	0.8	0.74	0.87
$C18^{(+)}$	1	1.11	1	1.11	1	1.11	1	1.11

Table 11 Alternatives ranking based on the FPIS and FNIS of each alternative and closeness coefficients

Alternatives	C_i	S_i^-	S_i^*	Ranking
A	0.637	18.42	10.47	1
B	0.628	17.33	10.26	2
C	0.591	15.23	10.54	3
D	0.500	11.36	11.35	4

of performance ranking of alternatives under all attributes is considered (MacCrimmon 1968; Chen and Hwang 1992).

In this study, the calculations of the SAW method are done following established methods (Podvezko 2011; Afshari et al. 2010). We used Shannon's entropy method to calculate the weights for normalizing the decision-making matrix (Shannon 2001). The calculations of ELECTRE III

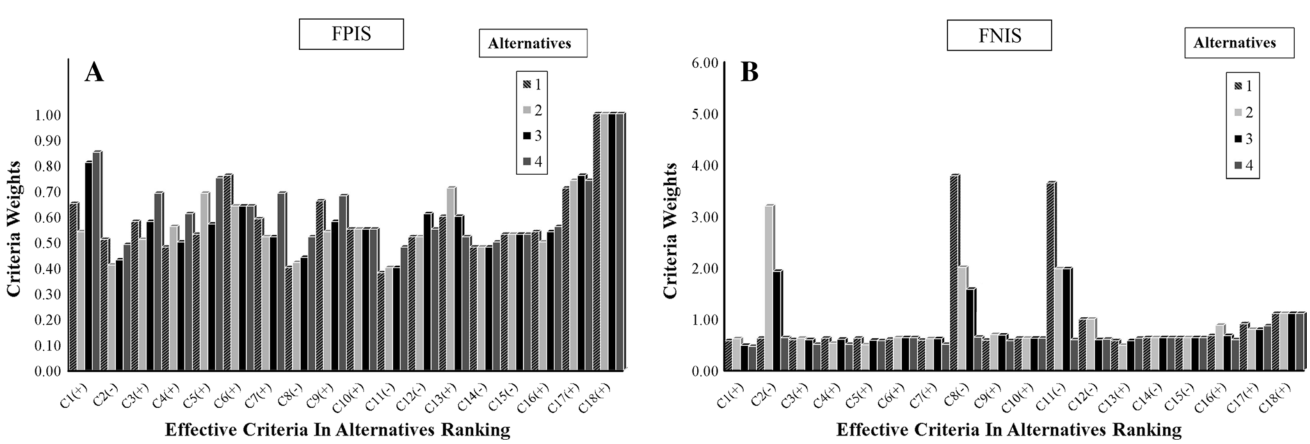

Fig. 4 Effect of the criteria on each alternative in terms of distance from FPIS and FNIS

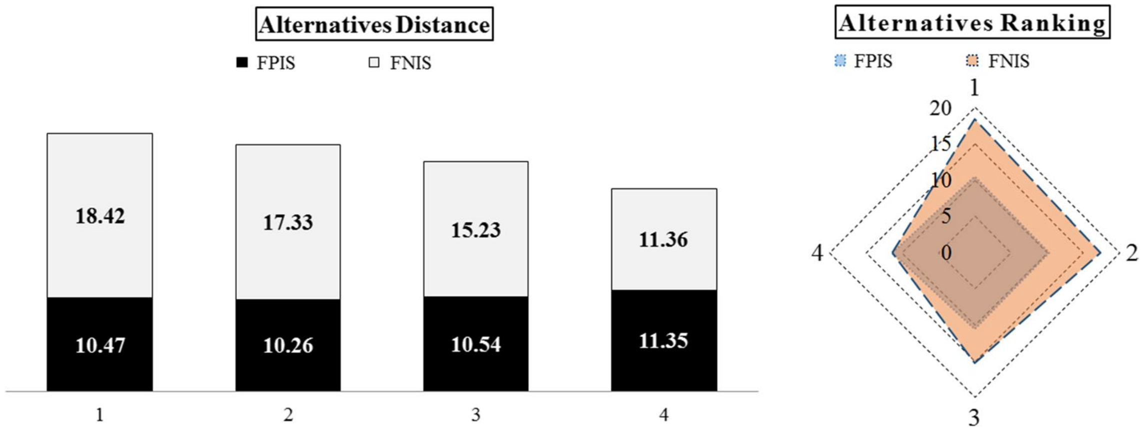

Fig. 5 Total effect of the criteria on each alternative in terms of distance from FPIS and FNIS

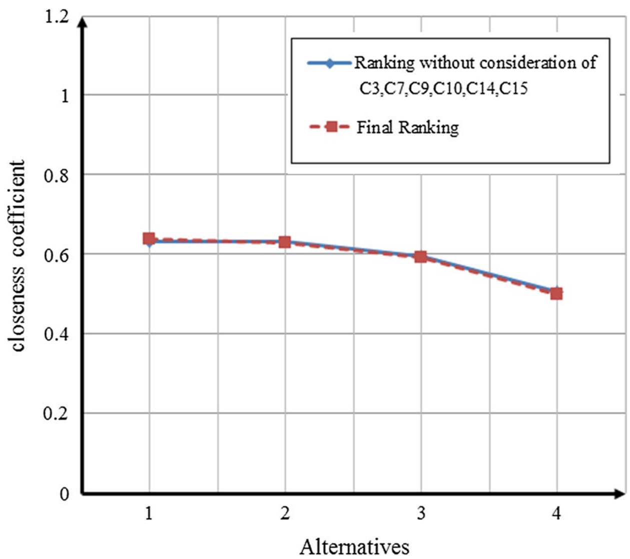

Fig. 6 A comparison of final ranking with ranking without considering C3, C7, C9, C10, C14 and C15 criteria

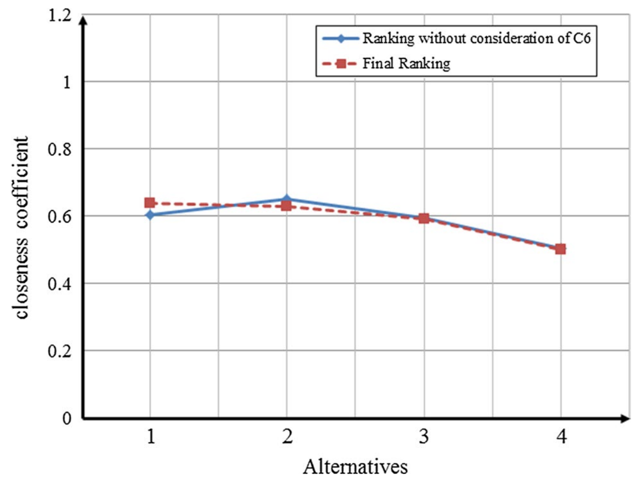

Fig. 7 Comparison of final ranking with ranking without considering the effect of C6 criterion

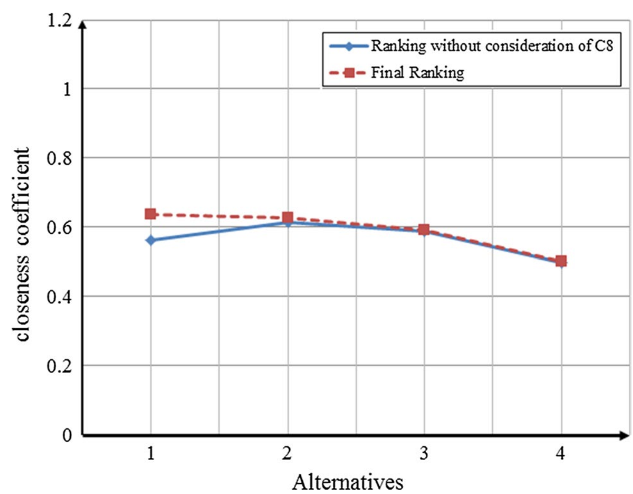

Fig. 8 Comparison of final ranking with ranking without considering the effect of C8 criterion

method were done following established methods (Figueira et al. 2005).

The rank of the alternatives calculated using the SAW and ELECTRE III methods is presented in Table 13. Comparing the rankings of the alternative sites calculated using the fuzzy TOPSIS method with the SAW and the ELECTRE III methods reveals significant differences among the three popular methods (see Table 14). These differences appearing in the rankings are due to the effect of each criterion in relation to each other and by ignoring the effect of group decision making in the process. Moreover, based on outranking and non-compensatory approaches that ELECTRE III benefits from, alternatives ranking is set to be different. For example, economy development criterion possesses the highest importance according to experts' opinions, but

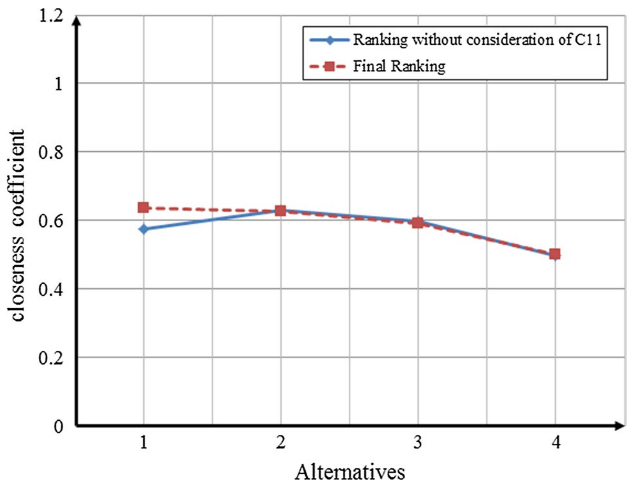

Fig. 9 Comparison of final ranking with ranking without considering the effect of C11 criterion

Table 12 Alternatives ranking without considering the importance weight of each criterion

Not considering the importance of weight changes for each criterion	Alternatives ranking
C3, C7, C9, C10, C14, C15	A, B, C, D
C1, C2	A, C, B, D
C6, C8, C11	B, C, A, D
C4, C5, C12, C13, C16, C17, C18	A, B, D, C
Considering all criteria	A, B, C, D

this importance cannot compensate the lower importance of environmental criterion of the alternative A in relation to alternative D. So, alternative A falls to the second rank and alternative D is placed in the first rank. In the employed fuzzy TOPSIS method, we used a group decision making to calculate the value of correlation coefficient.

Finally, comparing the alternative site ranking results for the fuzzy TOPSIS method with the SAW and the ELECTRE III methods, we conclude that the fuzzy TOPSIS method benefits from a more comprehensive evaluation approach resulting in a superior site ranking method with a higher degree of precision compared with the other two aforementioned popular methods.

6 Conclusion

This paper presents the first-time applications of the novel combination of the MCDM methods with fuzzy logic to solve the optimal dam site selection problem with complex multi-criteria considerations, including: social, economic and environmental constraints and criteria. We present the application of the group decision-making model fuzzy TOPSIS with TFNs to incorporate the level of uncertainties in data and intricate, complex opinions of the key stakeholders to select the optimal dam site using a logical, open and transparent science-informed decision-making framework. To showcase the application of the new method, the Kandoleh optimal dam site selection case study was selected, located in the northwest of Iran, Kermanshah province. The optimal dam site was determined using the implemented method and considering effective criteria. The selected optimal site was evaluated by dam site selection experts involving in the Kandoleh dam project so that selected site has also been confirmed by them indicating the appropriate performance of this model in the selection of the optimal site. Obtained results showed that the key criteria such as transmission and water diversion, economic development and reservoir and body damages play significant roles in the selection of the dam site. Meanwhile, few criteria including hydrologic criterion, water resource quality, reservoir capacity, river flow regime, the probable maximum flood and weather condition play the lowest impact in comparison with the others.

Table 13 Criteria weight in each alternative using in the SAW and ELECTRE III models

Criteria	SAW model based (Podvezko 2011; Afshari et al. 2010)					ELECTRE III model based (Figueira et al. 2005)				
	Alternatives					Alternatives				
	A	B	C	D	Weight of criteria	A	B	C	D	The importance of criteria
C1	0.046	0.033	0.053	0.059	0.048	0.143	0.286	0.286	0.286	15
C2	0.063	0.039	0.045	0.063	0.053	0.441	0.284	0.143	0.131	16
C3	0.040	0.033	0.046	0.059	0.045	0.375	0.125	0.125	0.375	12
C4	0.033	0.046	0.039	0.059	0.044	0.141	0.141	0.263	0.455	12
C5	0.035	0.062	0.062	0.062	0.054	0.103	0.218	0.218	0.461	16
C6	0.054	0.054	0.053	0.053	0.055	0.392	0.144	0.144	0.320	20
C7	0.042	0.030	0.036	0.054	0.041	0.185	0.097	0.185	0.532	15
C8	0.020	0.020	0.026	0.059	0.031	0.594	0.145	0.208	0.053	16
C9	0.051	0.028	0.033	0.050	0.041	0.326	0.099	0.325	0.250	12
C10	0.053	0.053	0.053	0.053	0.053	0.333	0.174	0.272	0.220	8
C11	0.019	0.024	0.024	0.056	0.030	0.606	0.157	0.157	0.081	14
C12	0.025	0.029	0.046	0.046	0.036	0.470	0.136	0.114	0.280	15
C13	0.046	0.053	0.053	0.053	0.051	0.079	0.372	0.372	0.176	11
C14	0.033	0.027	0.033	0.055	0.037	0.452	0.212	0.143	0.193	14
C15	0.053	0.053	0.052	0.052	0.053	0.070	0.281	0.333	0.316	11
C16	0.044	0.029	0.037	0.051	0.041	0.193	0.127	0.162	0.517	17
C17	0.045	0.052	0.06	0.06	0.054	0.070	0.224	0.483	0.224	18
C18	0.049	0.049	0.049	0.049	0.049	0.541	0.260	0.139	0.059	10
The final weight of alternatives in SAW	0.752	0.717	0.801	0.993						

Table 14 Ranking of the alternative sites calculated using fuzzy TOPSIS, ELECTRE III and SAW methods

Ranking	Fuzzy TOPSIS	SAW	ELECTRE III
First priority	A	D	D
Second priority	B	C	A
Third priority	C	A	C
Fourth priority	D	B	B

Finally, comparison of the obtained results with the proposed site by project consultant was fairly consistent so that the dam will be constructed on this site (alternative 1), so this model can also be used to select another dam site.

Appendix 1: TFNs of experts' opinion about the criteria importance

See Table 15.

Table 15 TFNs of experts' opinion about the criteria importance

Criterion	Definition	Decision makers			
		D1	D2	D3	D4
C1	The safety of the site and reservoir	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)
C2	Total cost	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)
C3	Hydrologic criterion	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)
C4	Topographic conditions of the location	(0.5, 0.7, 0.9)	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)
C5	Accessibility to materials and facilities	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)
C6	Economic development	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)
C7	Water resource quality	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)
C8	Reservoir and body damages	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)
C9	Reservoir capacity	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)
C10	River flow regime	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)
C11	Transmission and water diversion	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)
C12	The annual volume of the reservoir sediment	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)
C13	The possibility of constructing workshop	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)
C14	The probable maximum flood	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)
C15	Weather condition	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)
C16	Environmental effects	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)
C17	Social acceptability	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)
C18	Political effects	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)

Appendix 2: TFNs of experts' opinion for evaluation of the alternatives in relation to criteria

See Table 16.

Table 16 TFNs of experts' opinion for evaluation of the alternatives in relation to criteria

Criteria	Decision makers	Alternatives			
		1	2	3	4
C1(+)	D1	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)	(7, 9, 10)
	D2	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(7, 9, 10)
	D3	(3, 5, 7)	(1, 3, 5)	(5, 7, 9)	(7, 9, 10)
	D4	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)	(5, 7, 9)
C2(-)	D1	(5, 7, 9)	(7, 9, 10)	(7, 9, 10)	(5, 7, 9)
	D2	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)
	D3	(5, 7, 9)	(7, 9, 10)	(3, 5, 7)	(1, 3, 5)
	D4	(1, 3, 5)	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)
C3(+)	D1	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
	D2	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)
	D3	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)
	D4	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
C4 (+)	D1	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
	D2	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)
	D3	(3, 5, 7)	(7, 9, 10)	(3, 5, 7)	(7, 9, 10)
	D4	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)	(7, 9, 10)
C5(+)	D1	(5, 7, 9)	(7, 9, 10)	(5, 7, 9)	(5, 7, 9)
	D2	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	D3	(1, 3, 5)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)
	D4	(3, 5, 7)	(7, 9, 10)	(1, 3, 5)	(5, 7, 9)

Table 16 (continued)

Criteria	Decision makers	Alternatives			
		1	2	3	4
C6(+)	D1	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	D2	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
	D3	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	D4	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
C7(+)	D1	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
	D2	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)
	D3	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)
	D4	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)	(7, 9, 10)
C8(-)	D1	(7, 9, 10)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)
	D2	(7, 9, 10)	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)
	D3	(7, 9, 10)	(7, 9, 10)	(5, 7, 9)	(3, 5, 7)
	D4	(7, 9, 10)	(7, 9, 10)	(5, 7, 9)	(3, 5, 7)
C9(+)	D1	(7, 9, 10)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
	D2	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)	(7, 9, 10)
	D3	(5, 7, 9)	(1, 3, 5)	(3, 5, 7)	(7, 9, 10)
	D4	(7, 9, 10)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
C10(+)	D1	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	D2	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
	D3	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
	D4	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
C11(-)	D1	(7, 9, 10)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)
	D2	(7, 9, 10)	(3, 5, 7)	(5, 7, 9)	(1, 3, 5)
	D3	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)
	D4	(7, 9, 10)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)
C12(-)	D1	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)
	D2	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)
	D3	(7, 9, 10)	(7, 9, 10)	(3, 5, 7)	(3, 5, 7)
	D4	(7, 9, 10)	(7, 9, 10)	(3, 5, 7)	(3, 5, 7)
C13(+)	D1	(5, 7, 9)	(7, 9, 10)	(5, 7, 9)	(5, 7, 9)
	D2	(5, 7, 9)	(7, 9, 10)	(5, 7, 9)	(3, 5, 7)
	D3	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)
	D4	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)
C14(-)	D1	(5, 7, 9)	(7, 9, 10)	(5, 7, 9)	(1, 3, 5)
	D2	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
	D3	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)
	D4	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)
C15(-)	D1	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
	D2	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
	D3	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	D4	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
C16(+)	D1	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)
	D2	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(7, 9, 10)
	D3	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
	D4	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(5, 7, 9)
C17(+)	D1	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)
	D2	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	D3	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	D4	(5, 7, 9)	(7, 9, 10)	(7, 9, 10)	(5, 7, 9)
C18(+)	D1	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
	D2	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)
	D3	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)
	D4	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)

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