Water Resources Management (2019) 33:5169–5190
https://doi.org/10.1007/s11269-019-02423-4

A Fuzzy Group Decision Making Framework Based on ISM-FANP-FTOPSIS for Evaluating Watershed Management Strategies

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Received: 17 January 2019 / Accepted: 12 November 2019 /
Published online: 27 November 2019

Abstract
Watershed planning and management is a complex process due to existing different influential criteria in social, economic and environmental sectors as well as complicated interactions among them. Therefore, evaluating watershed management programs needs a comprehensive approach considering network relations among criteria and diverse decision-makers' judgments. This paper presents a new framework of group decision-making in evaluating and ranking watersheds for implementing development strategies. The model includes 18 criteria in social, economic, managerial and environmental clusters. Five watersheds are considered as alternatives. At first, the network relations among the various criteria are determined using the Interpretive Structural Modeling (ISM) method. Then, based on the relationships obtained by ISM and decision-makers' judgments, the alternatives' priority is determined through the Fuzzy Analytic Network Process (FANP) method. To aggregate the group decision-making results, the extended fuzzy TOPSIS method is proposed and the decision-makers' weights are calculated using Shannon's entropy method. Finally, the sensitivity analysis of the decision-makers' weights and alternatives priorities have been conducted. The Monte Carlo method is applied to generate data for sensitivity analysis. According to the results, Urmia Lake is the most preferred watershed and Atrak watershed is ranked in last.

Keywords Interpretive structural modeling · Fuzzy analytic network process · Fuzzy TOPSIS · Watershed management · Monte Carlo

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1 Introduction

Watersheds are coupled human-natural systems characterized by interactions between human activities and natural processes (Cai et al. 2013). Watersheds are considered as the most effective unit. The integrated management of watersheds plays an important role in the protection and conservation of soil and water resources. Watershed management planners and water sector decision-makers often face the problem to deal with complex management decisions due to different influential factors as well as complicated interactions among them. Also, there are formidable challenges in terms of implementation development planning and strategies in watersheds. Thus, managers require the expansion of innovative methods and algorithms to assist them in understanding strategic decision making for effective watershed management.

One means of dealing with these problems within watersheds is MCDM[1] models. These methods have been extensively used in various researches in water resources and watershed management. Hajkowicz and Higgins (2008) compared the results of five MCDM methods for six water management decision problems. Zarghami et al. (2008) developed the extended OWA method for ranking water resources projects in Sefidrud watershed. Also, Zarghami et al. (2009) proposed a new version of Ordered Weighted Averaging (OWA) method for selecting inter-basin water transfer projects. Chang and Hsu (2009) used VIKOR[2] method for ranking land use restraint strategies in the Tseng-Wen reservoir watershed. RazaviToosi et al. (2009) applied fuzzy TOPSIS,[3] fuzzy max-min set and Bonissone's methods for evaluating water transfer projects. The fuzzy AHP[4] method is applied to determine the weights of criteria for selecting the best environment-watershed plan (Chen et al. 2011). Also, the AHP method is developed for improving the strategic environmental assessment of water programs (Garfi et al. 2011). Opricovic (2011) used the fuzzy VIKOR method for ranking water resources planning. RazaviToosi and Samani (2012) applied Analytical Network Process (ANP) method for ranking water transfer projects. Chowdary et al. (2013) used the AHP method and GIS for watershed prioritization. Furthermore, the AHP method is utilized for the effective selection of agricultural best management practices based on environmental, economic and social factors (Giri and Nejadhashemi 2014). A new integrated decision method is introduced for evaluating water transfer projects (RazaviToosi and Samani 2014). Jaiswal et al. (2015) prioritized susceptible areas in the watershed for soil conservation measures using fuzzy AHP based multi-criteria decision support. Sabbaghian et al. (2016) introduced a novel MCDM approach that analyzes the decision-making process at both the sub-basin and watershed levels. Also, a new fuzzy ANP method is proposed for ranking watersheds (RazaviToosi and Samani 2016, 2017). For evaluating sustainable management of a river basin, a decision support model is developed by coupling the fuzzy SWOT model and geostatistical approach (Srinivas et al. 2018). The AHP method is used to assess land use change impact on sub-watersheds prioritization (Kundu et al. 2017). Different multiple criteria decision-making models such as Simple Additive Weighing (SAW), TOPSIS, VIKOR and Compound Factor (CF) are applied for

[1] Multiple Criteria Decision Making
[2] VlseKriterijumska Optimizacija I Kompromisno Resenje
[3] Technique for Order of Preference by Similarity to Ideal Solution
[4] Analytical Hierarchy Process

erodibility prioritization of sub-watersheds in Iran (Arab Ameri et al. 2018). Besides, an integrated multi-criteria modeling framework is proposed for watershed prioritization in India (Jain and Ramsankaran 2019).

According to the literature, in more studies in water resources and watershed management fields, whether the casual relations among decision elements have not been considered or only been used ANP method without a systematic analysis of relations among the criteria. The first novelty of this paper is using Interpretive Structural Modeling (ISM) for evaluating network relations among decision elements. In recent years, ISM method has been applied in many decision problems such as: selection of supplier in the built-in-order supply chain environment (Kannan and Haq 2007), evaluating municipal solid waste management problems (Liao and Chiu 2011), analysis of third- party reverse logistics provider (Govindan et al. 2012), appraisal of the barriers for the implementation of green supply chain management (Mathiyazhagan et al. 2013), evaluating agile supplier selection criteria (Beikkhakhian et al. 2015), assessing potential alternatives for sustainable supply chain management (Hussain et al. 2016), evaluating the performance of partnership to help companies to increase their competitiveness in a global market (Piltan and Sowlati 2016), etc.

In a group decision-making problem, the judgments of decision-makers are different. In many cases, the different weights of decision-makers have not been considered and usually equal weights are dedicated to all of them. The second novelty of this research is the use of Shannon's entropy method and extended the fuzzy TOPSIS algorithm to obtain the decision-maker weights and aggregate group decision-making results. Also, to evaluate the sensitivity of the alternatives to decision-makers' weights and judgments, the sensitivity analysis has been conducted using Monte Carlo method. The main purpose of this study is to introduce a new hybrid fuzzy decision model able to determine the complex relations among decision elements and their priorities using ISM and FANP methods and also to aggregate decision-makers' results, Shannon's entropy and FTOPSIS methods are applied. Finally, to evaluate the influence of decision-makers' weights and their judgments on the final results, the Monte Carlo method has been employed.

As a test case for applying the proposed model, five watersheds are evaluated based on developing strategies in social, economic, environmental and managerial.

The remainder of this paper is organized as follows. Section 2 describes the study area and the proposed decision model for evaluating alternatives. Section 3 contains the results and discussions. Finally, the main conclusion of the research is summarized in Section 4.

2 Materials and Methods

2.1 Study Area

Growing demand, population growth, water pollution, uneven distribution, droughts, climate change, etc. are the main challenges of water management that led to the water shortage. Considering water shortage in Iran, the main part of watershed management is focused on planning development strategies in the water resources sector. Watershed management is a process that involves planning and implementation of strategies to reach one or more of development objectives. The challenge of this issue is due to a lack of financial and human resources, development strategies cannot be executed in all watersheds, simultaneously. On the other hand, different and inconsistent criteria, as well as inner and outer relations among them, have increased the complexity of the problem. Thus, it is necessary to find a way which is not only considered interactions among criteria, but also ranked watersheds for employing development strategies.

Owing to the above discussion and the importance of effective implementation of development strategies in watersheds, the main purpose of this study is to present a comprehensive novel model for ranking watersheds. As a test case for applying the proposed model, five watersheds named Urmia Lake (A_1), Atrak (A_2), Namak Lake (A_3), Sefidrood (A_4) and Zayanderood (A_5), are evaluated by developing and employing strategies in social, economic, environmental and managerial. Urmia Lake watershed is located in the northwest of Iran. The total area of this basin is 51,761 Km^2. The lake is the second-largest hyper-saline lake worldwide and one of the most important aquatic ecosystems in the country. Due to drought and climate change, dam constructions, increasing irrigated farming, over-exploitation of groundwater and generally, poor water management, the lake basin is facing extreme water shortages.

The Atrak watershed is located in the east of the water catchment area of the Caspian Sea. The total area of this basin is 26,395 Km^2. Parts of the Atrak river basin are located in Turkmenistan and its main tributary in Turkmenistan named Sombar River which forms Iran and Turkmenistan border in North Khorasan Province. The Atrak watershed is one of the critically affected watersheds where unplanned use of water resources, excessive tree felling, overgrazing, and road construction lead to increased erosion and decreased productivity in the watershed. The Namak watershed with 92,884 Km^2 area is located in the northeast of central Iran. In this basin, due to the development of industrial cities in this watershed and over-use of groundwater, groundwater resources are facing serious crisis.

The Sefidrood River with 59,194 Km^2 area is located in the northwestern part of Iran. One of the main challenges in this watershed is environmental problems related to the quality and quantity of Sefidrood River. The Zayanderood is one of the most important river basins in semi-arid central Iran. The total area of this strategic river basin is 41,552 Km^2. Water demand is rising annually due to population growth, increasing irrigated farming and industrial development. Therefore, the Zayanderood River downstream is completely dry in some seasons.

All the selected watersheds in this study are in danger of drying out and need development attempts for protection and survival. Also, 18 development strategies are defined in social, environmental, economic and managerial sectors for evaluating watersheds. More details about strategies are explained in Section 3.

2.2 The Proposed Flow Diagram

In this study, a modeling framework is developed for group decision making based on ISM, fuzzy ANP, Shannon's entropy, and modified fuzzy TOPSIS method. The procedure of the proposed method is shown in Fig. 1. As it can be seen, after defining decision-making model included watersheds as alternatives and development strategies as criteria, the network relations are determined using the ISM method. The output of the ISM method is applied to construct pairwise comparison matrices and provide questionnaires as the first step of the fuzzy ANP method. The questionnaires are completed by 6 decision-makers. Therefore, the outputs of the fuzzy ANP method include watersheds and development priorities based on different decision-makers' judgments. Since the weights of decision-makers are different, the Shannon's Entropy and extended fuzzy TOPSIS method are used to aggregate the group decision-making results. Finally, to provide accurate decisions, the Monte Carlo method is applied to generate different data within the sensitivity analysis context. The details of the proposed method are described as follows.

Step1: at first, the goal, criteria, sub-criteria and alternatives are defined. The multiple attribute group decision making (MAGDM) method includes a set of n alternatives $A = \{A_1, A_2, \ldots, A_n\}$, m criteria $C = \{C_1, C_2, \ldots, C_m\}$ and K decision-maker $DM = \{DM_1, DM_2, .., DM_k\}$.

Step 2: After defining the criteria, the ISM method is used to understand the relations among the criteria. The questionnaires are completed by experts to determine the contextual relationships among attributes. Then, the Structural Self-Interaction Matrix (SSIM) is constructed. The relations between attributes i and j are determined by four symbols as follows (Govindan et al. 2012).

V: attribute i will help to alleviate attribute j, A: attribute i will be alleviated by attribute j, X: attributes i and j will help to achieve each other and O: attributes i and j are unrelated.

The SSIM is converted into a reachability matrix by replacing V, A, O, and X by 1 and 0 based on the following rules.

If $(i,j) = V$ then the (i,j) becomes 1 and (j,i) becomes 0.

If $(i,j) = A$ then (i,j) becomes 0 and (j,i) becomes 1.

If $(i,j) = X$ then (i,j) and (j,i) become 1.

If $(i,j) = O$ then (i,j) and (j,i) become 0.

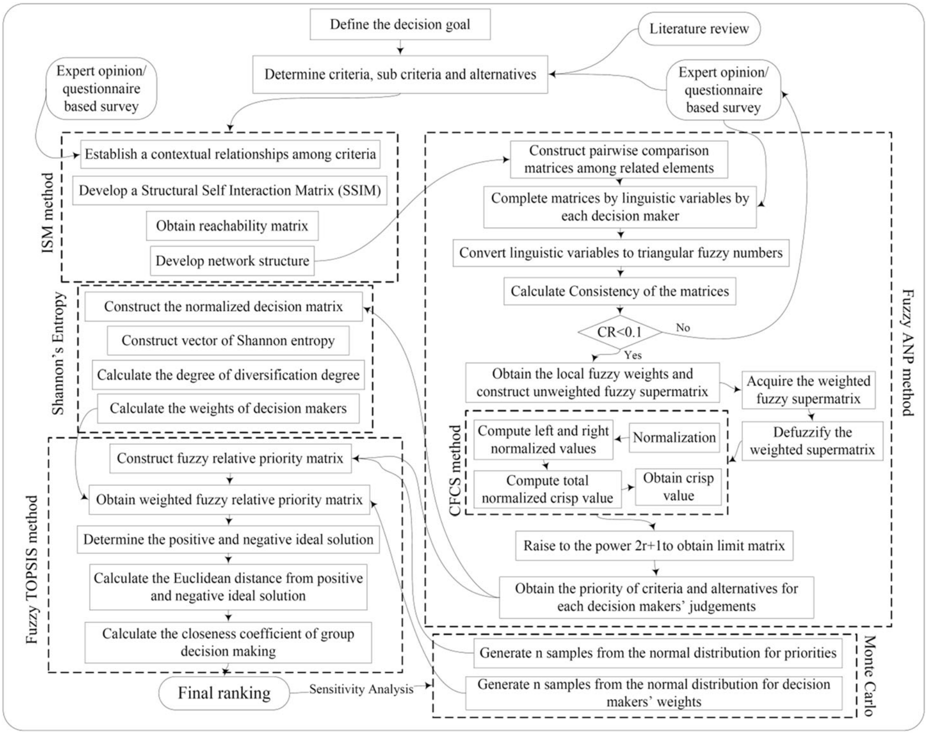

Fig. 1 Procedure of hybrid decision-making method

The general form of this matrix is shown in Eq. (1), where π_{ij} denotes the relations among i^{th} and j^{th} criteria.

$$D = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_m \end{array} \begin{array}{c} c_1 \quad c_2 \quad \dots \quad c_m \\ \begin{bmatrix} 0 & \pi_{12} & \dots & \pi_{1m} \\ \pi_{21} & 0 & \cdots & \pi_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ \pi_{m1} & \pi_{m2} & \cdots & 0 \end{bmatrix} \end{array} \tag{1}$$

Then, the initial reachability matrix (M) is calculated by adding matrix D with the unit matrix (I) as follows.

$$M = D + I \tag{2}$$

The final reachability matrix (M^*) is obtained from the initial reachability matrix taking into account the transitivity rule.

$$M^* = M^q = M^{q+1} \quad , \ q > 1 \tag{3}$$

Using the operators of the Boolean multiplication and addition (i.e. $1 \times 1 = 1$, $1 \times 0 = 0 \times 1 = 0$, $0 \times 0 = 0$, $1 + 1 = 1$, $1 + 0 = 0 + 1 = 1$, and $0 + 0 = 0$), the convergence can be obtained.

Finally, the network model is determined based on the relationships of the criteria given in the final reachability matrix.

Step 3: based on the network relations obtained by the ISM method, the pairwise comparison matrices are constructed. Then the questionnaires are provided to decision-makers and completed using linguistic terms as shown in Table 1.

For each matrix, the value of consistency ratio (CR) should be less than 0.1 (Saaty 1996). Otherwise, the result is not consistent and the pairwise comparison is completed again. Next, the relative fuzzy weights are calculated for constructing fuzzy supermatrix as follows (Tuzkaya et al. 2009):

$$\widetilde{w}_r = \left(w_r^l, w_r^m, w_r^u\right) \quad k = 1, 2, \dots, n \tag{4}$$

Table 1 Linguistic terms and corresponding crisp and fuzzy values

Linguistic term	Scale of relative importance	
	Crisp value (Saaty 1996)	Triangular fuzzy number (Mohaghar et al. 2012)
Equal importance	1	(1,1,1)
Moderate importance	3	(2,3,4)
Strong importance	5	(4,5,6)
Very strong importance	7	(6,7,8)
Extreme importance	9	(8,9,10)
Intermediate scales	2,4,6	(x-1,x,x + 1)

where

$$w_r^s = \frac{\left(\prod_{j=1}^n a_{kj}^s\right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n a_{ij}^m\right)^{1/n}} \quad , \ s \in \{l, m, u\}$$
$$i = 1, 2, ..., n \quad , \quad j = 1, 2, ..., n \tag{5}$$

The unweighted fuzzy supermatrix is formed by entering the fuzzy local weights into the appropriate columns. The weighted fuzzy supermatrix is obtained by multiplying the components of the unweighted fuzzy supermatrix to the corresponding cluster weights. Then, the triangular fuzzy numbers are converted to crisp values using converting fuzzy data into crisp scores (CFCS) method proposed by Opricovic and Tzeng (2003). Let $\widetilde{f}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ indicates the fuzzy preference degree among criterion i and criterion j. The crisp value could be determined by the following four-steps CFCS algorithm.

a) Normalization:

$$x\widetilde{f}_j = \left(\widetilde{f}_{ij} - \min l_{ij}\right) / \left(\max_j u_{ij} - \min_j l_{ij}\right) \tag{6}$$

b) Compute left (ls) and right (rs) normalized values:

$$xls_j = xm_j / \left(1 + xm_j - xl_j\right) \tag{7}$$

$$xrs_j = xu_j / \left(1 + xu_j - xm_j\right) \tag{8}$$

c) Compute total normalized crisp values:

$$x_j^{crisp} = \left[xls_j\left(1 - xls_j\right) + xrs_j.xrs_j\right] / \left[1 - xls_j + xrs_j\right] \tag{9}$$

d) Obtain crisp values:

$$f_{ij} = \min_j l_{ij} + \left(x_j^{crisp}.\left(\max_j u_{ij} - \min_j l_{ij},\right)\right) \tag{10}$$

Step 4: the weighted supermatrix is normalized and raised to the power of $2r+1$ to reach a limit supermatrix where all the columns are the same. r indicates an arbitrarily large number. The final priority based on each decision-maker judgment is shown as follows:

$$DM^{k}{}_{(A)} = \left\{p^{k}\,(A_1), p^{k}\,(A_2), \ldots, p^{k}\,(A_n)\right\} \tag{11}$$

$$DM^{k}{}_{(C)} = \left\{w^{k}\,(C_1), w^{k}\,(C_2), \ldots, w^{k}\,(C_n)\right\} \tag{12}$$

where $p^k\ (A_1)$ and $w^k\ (C_1)$ denote alternatives priority and criteria weights obtained by decision- maker k ($k = 1,2,.., K$), respectively.

To obtain the final priority of alternatives, the scores of aggregated evaluations of group decision- makers are required. To this end, a new methodology based on the fuzzy TOPSIS algorithm by considering the decision-makers' weights is proposed.

Step 5: the weight of each decision-maker is determined by Shannon's entropy method. After obtaining the priority of alternatives based on each decision-makers' judgments $(p^k(A_n))$, the decision making matrix ($p_{ik}(A_i)$) is constructed. The normalized value for decision-making matrix is calculated by the following formula:

$$PN_{ik} = \frac{P_{ik}\left(A_{(i)}\right)}{\sum_{i=1}^{n} P_{ik}(A_i)} \tag{13}$$

Then, the entropy value of decision-maker (E_k) and the value of deviation (d_k) are obtained as below:

$$E_k = -(Ln\,(n))^{-1} \sum_{i=1}^{n} [(PN_{ik}).Ln\,(PN_{ik})] \tag{14}$$

$$d_k = 1 - E_k \tag{15}$$

Table 2 Linguistic variables in fuzzy TOPSIS method (Chen 2000)

Crisp value	Conceptual phrases	Triangular fuzzy numbers
1	Very low	(0,0,1)
2	Low	(0,1,3)
3	Moderate low	(1,3,5)
4	Moderate	(3,5,7)
5	Moderate high	(5,7,9)
6	High	(7,9,10)
7	Very high	(9,10,10)

Finally, the weights of decision-makers are calculated by the following relationship:

$$w_k = \frac{d_k}{\sum_{k=1}^{K} d_k} \tag{16}$$

Step 6: in this step, the fuzzy TOPSIS method is used to determine the final ranking. The priority of each alternative obtained by the fuzzy ANP method in step 4 *($p^k(A_i)$)* is converted to a triangular fuzzy number (Table 2) and the following fuzzy relative priority matrix is constructed.

$$\widetilde{P} = \begin{bmatrix} \widetilde{p}^{1}(A_1) & \widetilde{p}^{2}(A_1) & \dots & \widetilde{p}^{K}(A_1) \\ \widetilde{p}^{1}(A_2) & \widetilde{p}^{2}(A_2) & \cdots & \widetilde{p}^{K}(A_2) \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{p}^{1}(A_n) & \widetilde{p}^{2}(A_n) & \cdots & \widetilde{p}^{K}(A_n) \end{bmatrix} \tag{17}$$

The weighted fuzzy relative priority matrix is constructed by incorporating the weights of decision-makers obtained by Shannon's entropy method (step 5) into a fuzzy relative priority matrix.

$$\widetilde{P}_\alpha = \begin{bmatrix} w_1\widetilde{p}^{1}(A_1) & w_2\widetilde{p}^{2}(A_1) & \dots & w_K\widetilde{p}^{K}(A_1) \\ w_1\widetilde{p}^{1}(A_2) & w_2\widetilde{p}^{2}(A_2) & \cdots & w_K\widetilde{p}^{K}(A_2) \\ \vdots & \vdots & \vdots & \vdots \\ w_1\widetilde{p}^{1}(A_n) & w_2\widetilde{p}^{2}(A_n) & \cdots & w_K\widetilde{p}^{K}(A_n) \end{bmatrix} \tag{18}$$

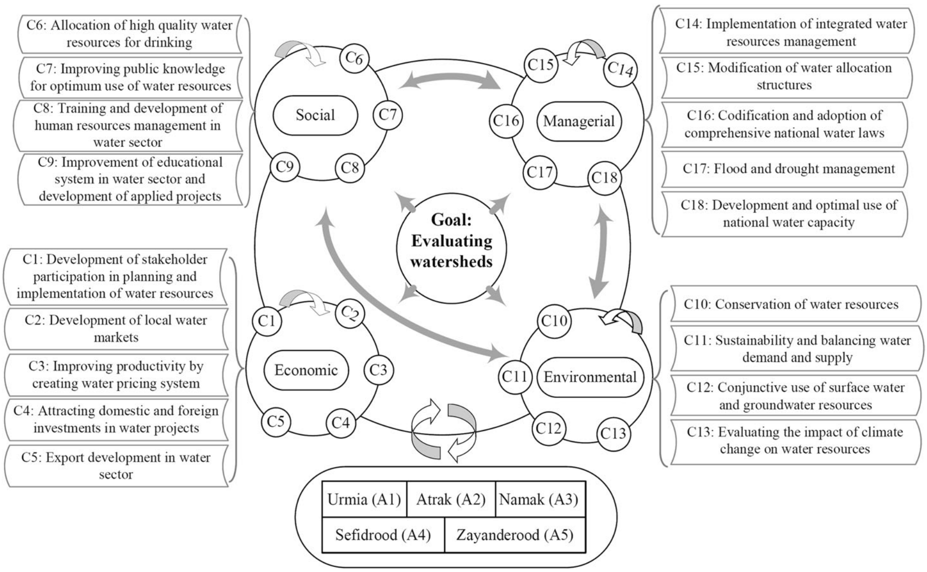

Fig. 2 Decision-making model structure

Table 3 Part of SSIM and initial reachability matrices

	SSIM					Initial reachability matrix				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
C1	–					0	0	0	0	0
C2	V	–				1	0	0	0	0
C3	O	O	–			0	0	0	1	0
C4	V	V	X	–		1	1	1	0	0
C5	O	O	O	V	–	0	0	0	1	0

The positive and negative ideal solution for group decision-maker is obtained as follows.

$$\tilde{A}_G^+ = \left\{ \max_i w_1 \tilde{p}^1(A_i), \max_i w_2 \tilde{p}^2(A_i), \dots, \max_i w_K \tilde{p}^K(A_i) \right\} = \left\{ \tilde{A}_{G1}^+, \tilde{A}_{G2}^+, \dots, \tilde{A}_{GK}^+ \right\} \quad (19)$$

$$\tilde{A}_G^- = \left\{ \min_i w_1 \tilde{p}^1(A_i), \min_i w_2 \tilde{p}^2(A_i), \dots, \min_i w_K \tilde{p}^K(A_i) \right\} = \left\{ \tilde{A}_{G1}^-, \tilde{A}_{G2}^-, \dots, \tilde{A}_{GK}^- \right\} \quad (20)$$

Then, the Euclidean distance of each alternative from $\tilde{A}_G^+$ and $\tilde{A}_G^-$ based on group decision making is obtained.

$$d_{Gi}^+ = \sum_{k=1}^K d\left(w_k \tilde{p}^k(A_i), \tilde{A}_{Gk}^+ \right), d_{Gi}^- = \sum_{k=1}^K d\left(w_k \tilde{p}^k(A_i), \tilde{A}_{Gk}^- \right) \quad (21)$$
$$i = 1, 2, \dots, n \quad , \quad k = 1, 2, \dots, K$$

Finally, the final ranking of alternatives through closeness coefficient in group decision making is calculated.

$$CC_G(A_i) = \frac{d_{Gi}^-}{d_{Gi}^+ + d_{Gi}^-} \quad (22)$$

Step 7: when all priorities are calculated, to evaluate how the ranking of the alternatives changes under any condition, a set of priorities and decision-makers' weights are generated completely randomly. In this regard, the Monte Carlo method is used for generating initial data. At first, N samples from a normal distribution is generated for $p^k(A_i)$ and w_k.

Table 4 Pairwise comparison matrices among criteria in managerial and environmental with respect to C_{14}

	Environmental					Managerial			
	C_{10}	C_{11}	C_{12}	Local weights		C_{15}	C_{17}	C_{18}	Local weights
C_{10}	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(0.21,0.29,0.43)	C_{15}	(1,1,1)	(1,2,3)	(4,5,6)	(0.43,0.58,0.71)
C_{11}	(1,2,3)	(1,1,1)	(2,3,4)	(0.37,0.54,0.68)	C_{17}	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(0.24,0.31,0.43)
C_{12}	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(0.13,0.16,0.24)	C_{18}	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(0.09,0.11,0.13)

Table 5 Part of the unweighted fuzzy supermatrix by *DM1*

		A_1	A_2	…	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}
Alternative	A_1	(0,0,0)	(0,0,0)	…	(0.19,0.33,0.46)	(0.15,0.17,0.19)	(0.19,0.33,0.46)	(0.21,0.34,0.46)	(0.27,0.39,0.51)
	A_2	(0,0,0)	(0,0,0)	…	(0.15,0.17,0.19)	(0.15,0.17,0.19)	(0.15,0.17,0.19)	(0.07,0.09,0.16)	(0.11,0.12,0.15)
	A_3	(0,0,0)	(0,0,0)	…	(0.15,0.17,0.19)	(0.19,0.33,0.46)	(0.15,0.17,0.19)	(0.15,0.24,0.35)	(0.11,0.12,0.15)
	A_4	(0,0,0)	(0,0,0)	…	(0.15,0.17,0.19)	(0.15,0.17,0.19)	(0.15,0.17,0.19)	(0.12,0.16,0.23)	(0.11,0.12,0.15)
	A_5	(0,0,0)	(0,0,0)	…	(0.15,0.17,0.19)	(0.15,0.17,0.19)	(0.15,0.17,0.19)	(0.12,0.16,0.23)	(0.14,0.23,0.34)
Economic	C_1	(0.24,0.32,0.38)	(0.29,0.41,0.52)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
	C_2	(0.24,0.32,0.38)	(0.1,0.13,0.18)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
	C_3	(0.11,0.17,0.26)	(0.15,0.24,0.34)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
	C_4	(0.08,0.11,0.16)	(0.1,0.13,0.18)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
	C_5	(0.06,.07,0.11)	(0.06,.07,0.11)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
Social	C_6	(0.17,0.19,0.22)	(0.03,0.37,0.43)	…	(1,1,1)	(1,1,1)	(1,1,1)	(0,0,0)	(0,0,0)
	C_7	(0.32,0.46,0.59)	(0.31,0.37,0.43)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
	C_8	(0.16,0.17,0.19)	(0.11,0.15,0.18)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
	C_9	(0.16,0.17,0.19)	(0.11,0.12,0.15)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
Environmental	C_{10}	(0.17,0.23,0.29)	(0.23,0.33,0.41)	…	(0.21,0.29,0.43)	(0.21,0.29,0.43)	(0.33,0.33,0.33)	(0,0,0)	(0,0,0)
	C_{11}	(0.27,0.42,0.56)	(0.23,0.33,0.41)	…	(0.37,0.54,0.68)	(0.37,0.54,0.68)	(0.33,0.33,0.33)	(0,0,0)	(0,0,0)
	C_{12}	(0.17,0.23,0.3)	(0.14,0.17,0.24)	…	(0.13,0.16,0.24)	(0.13,0.16,0.24)	(0.33,0.33,0.33)	(0,0,0)	(0,0,0)
	C_{13}	(0.09,0.12,0.19)	(0.14,0.17,0.24)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
Managerial	C_{14}	(0.28,0.41,0.52)	(0.37,0.48,0.57)	…	(0,0,0)	(0,0,0)	(0.32,0.46,0.57)	(0,0,0)	(0,0,0)
	C_{15}	(0.17,0.22,0.28)	(0.22,0.28,0.37)	…	(0.43,0.58,0.71)	(0,0,0)	(0.21,0.29,0.41)	(0,0,0)	(0,0,0)
	C_{16}	(0.07,0.08,0.11)	(0.06,0.07,0.1)	…	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
	C_{17}	(0.15,0.2,0.27)	(0.07,0.11,0.14)	…	(0.24,0.31,0.43)	(0,0,0)	(0.13,0.17,0.24)	(0,0,0)	(0,0,0)
	C_{18}	(0.06,0.07,0.09)	(0.04,0.05,0.07)	…	(0.09,0.11,0.13)	(1,1,1)	(0.07,0.08,0.09)	(0,0,0)	(0,0,0)

The mean demonstrates the value of elements and the standard deviation represents 10% of the element value. Then, based on generated data, the fuzzy relative priority matrix is constructed and the final scores of alternatives are determined.

3 Results and Discussion

The proposed hybrid fuzzy group decision-making model is used for evaluating watersheds. At first, the effective criteria and sub-criteria are defined by the comprehensive review of the

Table 6 The cluster weights

	Alternatives	Economic	Social	Environmental	Managerial
Alternatives	(0,0,0)	(0.47,0.66,0.81)	(0.29,0.44,0.57)	(0.29,0.44,0.57)	(0.41,0.57,0.7)
Economic	(0.27,0.42,0.56)	(0.27,0.33,0.47)	(0,0,0)	(0,0,0)	(0,0,0)
Social	(0.09,0.12,0.19)	(0,0,0)	(0.08,0.11,0.17)	(0.08,0.11,0.17)	(0.11,0.14,0.19)
Environmental	(0.17,0.22,0.29)	(0,0,0)	(0.17,0.22,0.29)	(0.17,0.22,0.29)	(0,0,0)
Managerial	(0.17,0.22,0.29)	(0,0,0)	(0.17,0.22,0.29)	(0.17,0.22,0.29)	(0.19,0.28,0.41)

Table 7 The weighted supermatrix by *DM1* defuzzified using CFCS method

		Al	A2	A3	A4	A5	Cl	C2	C3	C4	C5	C6
Alternatives	Al	0	0	0	0	0	0,129	0,244	0,169	0,129	0,193	0,123
	A2	0	0	0	0	0	0,129	0,077	0,094	0,082	0,116	0,073
	A3	0	0	0	0	0	0,129	0,179	0,169	0,233	0,134	0,123
	A4	0	0	0	0	0	0,129	0,70	0,121	0,111	0,116	0,123
	A5	0	0	0	0	0	0,129	0,130	0,133	0,129	0,116	0,123
Economic	CI	0,135	0,175	0,152	0,162	0,171	0	0,342	0,188	0,196	0,152	0
	C2	0,135	0,062	0,087	0,076	0,065	0	0	0,113	0,089	0,085	0
	C3	0,81	0,110	0,087	0,098	0,114	0	0	0	0,075	0,085	0
	C4	0,52	0,062	0,087	0,077	0,065	0	0	0,063	0	0,047	0
	C5	0,35	0,034	0,024	0,034	0,026	0	0	0	0	0	0
Social	C6	0,46	0,089	0,048	0,084	0,042	0	0	0	0	0	0
	C7	0,110	0,089	0,097	0,084	0,042	0	0	0	0	0	0
	C7	0,110	0,089	0,097	0,084	0,042	0	0	0	0	0	0
	C8	0,041	0,030	0,048	0,027	0,080	0	0	0	0	0	0
	C9	0,041	0,030	0,048	0,049	0,080	0	0	0	0	0	0
Environmental	C10	0,031	0,045	0,026	0,047	0,045	0	0	0	0	0	0
	C11	0,059	0,045	0,056	0,047	0,045	0	0	0	0	0	0
	C12	0,031	0,023	0,026	0,015	0,023	0	0	0	0	0	0
	C13	0,017	0,023	0,026	0,027	0,023	0	0	0	0	0	0
Managerial	C14	0,098	0,114	0,082	0,0104	0,100	0	0	0	0	0	0
	C15	0,054	0,070	0,082	0,069	0,064	0	0	0	0	0	0
	C16	0,020	0,018	0,019	0,020	0,021	0	0	0	0	0	0
	C17	0,050	0,026	0,045	0,039	0,038	0	0	0	0	0	0
	C18	0,018	0,013	0,012	0,011	0,021	0	0	0	0	0	0

	C7	C8	C9	C10	C10	C11	C12	C13	C14	C15	C16	C17	C18
Alternatives	0,202	0,182	0,167	0,159	0,159	0,160	0,165	0,131	0,152	0,077	0,152	0,154	0,175
	0,051	0,060	0,056	0,084	0,084	0,040	0,035	0,044	0,077	0,077	0,077	0,049	0,058
	0,153	0,182	0,167	0,088	0,088	0,121	0,108	0,131	0,077	0,152	0,077	0,115	0,058
	0,096	0,060	0,097	0,068	0,068	0,075	0,048	0,077	0,077	0,077	0,077	0,077	0,058
	0,096	0,111	0,097	0,068	0,068	0,075	0,108	0,077	0,077	0,077	0,077	0,077	0,113

Table 7 (continued)

	C7	C8	C9	C10	C10	C11	C12	C13	C14	C15	C16	C17	C18
Economic	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
Social	0	0	0	0	0	0,221	0,221	0	0,221	0,221	0221	0	0221
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0,287	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0,082	0,043	0	0,038	0,038	0,039	0	0
Environmental	0,150	0,150	0	0	0	0	0,082	0	0,067	0,067	0,039	0	0
	0	0	0	0	0	0,043	0	0	0,020	0,020	0,039	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0,148	0	0	0	0	0	0	0	0	0	0
Managerial	0	0	0	0	0	0	0	0	0	0	0,107	0	0
	0	0	0	0	0	0,180	0,180	0	0,134	0	0,071	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0,076	0	0,042	0	0
	0	0	0	0	0	0,046	0,046	0	0,025	0,221	0,018	0	0

Table 8 Limit matrix by *DM1*

		A1	A2	A3	A4	A5	C1	C2	C3	C4	C5	C6
Alternatives	A1	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184
	A2	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625
	A3	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034
	A4	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748
	A5	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821
Economic	C1	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091
	C2	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043
	C3	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040
	C4	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030
	C5	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012
Social	C6	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057
	C7	0,034	0,034	0,034	0,034	0,034	0,037	0,036	0,036	0,036	0,036	0,037
	C8	0,025	0,025	0,025	0,025	0,025	0,026	0,026	0,026	0,026	0,026	0,026
	C9	0,019	0,019	0,019	0,019	0,019	0,021	0,020	0,020	0,020	0,020	0,021
Environmental	C10	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032
	C11	0,027	0,027	0,027	0,027	0,027	0,028	0,028	0,028	0,028	0,028	0,028
	C12	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013
	C13	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013
Managerial	C14	0,039	0,039	0,039	0,039	0,039	0,043	0,041	0,041	0,041	0,041	0,043
	C15	0,039	0,040	0,040	0,039	0,040	0,041	0,040	0,040	0,040	0,040	0,041
	C16	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008
	C17	0,019	0,020	0,020	0,019	0,020	0,021	0,020	0,020	0,020	0,020	0,021
	C18	0,018	0,018	0,018	0,018	0,018	0,018	0,018Q	0,018	0,018	0,018	0,018

	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
Alternatives	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184	0,1184
	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625	0,0625
	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034	0,1034
	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748	0,0748
	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821	0,0821
Economic	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091

Table 8 (continued)

	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043
	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040
	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030
	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012
Social	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057
	0,035	0,035	0,037	0,035	0,035	0,035	0,037	0,036	0,037	0,036	0,036	0,036
	0,026	0,026	0,026	0,026	0,026	0,026	0,026	0,026	0,026	0,026	0,026	0,026
	0,020	0,020	0,021	0,020	0,020	0,020	0,021	0,020	0,021	0,021	0,020	0,021
Environmental	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032	0,032
	0,027	0,028	0,028	0,027	0,027	0,027	0,028	0,028	0,028	0,028	0,028	0,028
	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013
	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013
Managerial	0,040	0,041	0,043	0,040	0,040	0,040	0,043	0,041	0,043	0,042	0,041	0,042
	0,040	0,040	0,041	0,040	0,040	0,040	0,041	0,040	0,041	0,041	0,040	0,041
	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008
	0,020	0,020	0,021	0,020	0,020	0,020	0,021	0,020	0,021	0,020	0,020	0,020
	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018

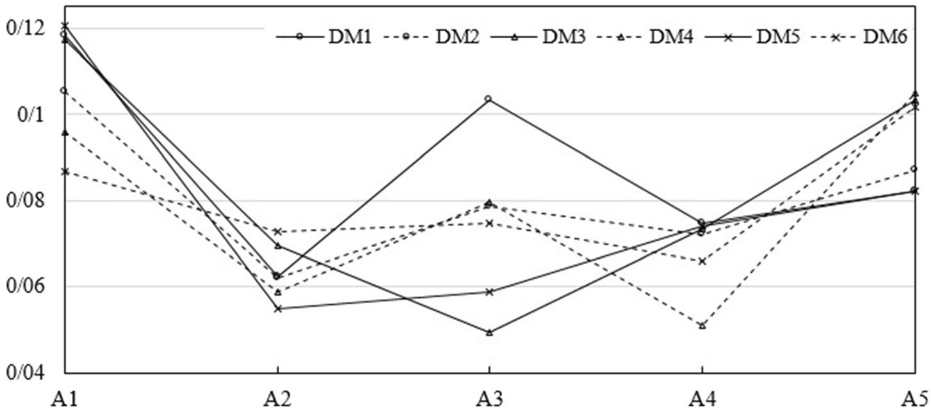

Fig. 3 The weights of watersheds obtained by decision-makers

literature and consultation with water management experts. Then, the decision model is constructed that includes watersheds and development strategies in social, economic, environmental and managerial as shown in Fig. 2. In this section, the results are presented step by step.

3.1 Network Relations

After defining alternatives and criteria, it is necessary to determine the network relations. To this end, the ISM model is used to understand the interactions among decision factors. The questionnaires were prepared to ask the relationship among one criterion to another and completed by experts to determine the contextual relationships among attributes. Then, the Structural Self-Interaction Matrix (SSIM) and initial reachability matrix are constructed. Due to space limitation, part of these matrices is shown in Table 3. The final reachability matrix for 18 criteria is obtained by incorporating transitivity. The relations among the criteria are depicted in Fig. 2.

3.2 FANP Results

Based on the network structure determined by ISM method, the pairwise comparison matrices are constructed. The questionnaires are completed by 6 decision-makers (DM)

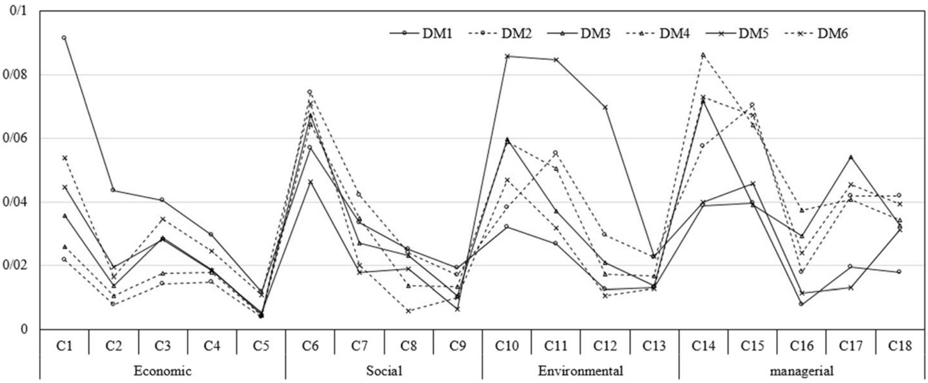

Fig. 4 The weights of strategies obtained by decision-makers

Table 9 The decision-maker weights obtained using Shannon's entropy method

	DM1	DM2	DM3	DM4	DM5	DM6
w	0.146	0.091	0.25	0.202	0.24	0.068

and used separately as input in the fuzzy ANP method. The comparisons need to be conducted are: comparisons of criteria with respect to other criteria, comparisons of alternatives with respect to each criterion and comparisons of criteria in each cluster by considering each alternative.

For example, based on the results of the ISM, implementation of integrated water resources management (C_{14}) is influenced by codification and adoption of comprehensive national water laws (C_{16}) and has an impact on C_6 in social cluster, C_{10}, C_{11}, C_{12} in the environmental cluster as well as C_{15}, C_{17}, C_{18} in managerial cluster. Therefore, to obtain the local weights of environmental related criteria (C_{10}, C_{11}, C_{12}) and managerial related criteria (C_{15}, C_{17}, C_{18}) with respect to C_{14}, the pairwise comparison matrices should be constructed. The similar matrices are constructed for all decision elements that influence each other. Table 4 shows the comparison matrices completed by *DM1* for obtaining local weights of criteria that influenced by C_{14}.

Now, the unweighted fuzzy supermatrix is formed using local weights obtained by pairwise comparison matrices based on each decision-makers' opinion. It is a square matrix of all alternatives and criteria in decision model (shown in Fig. 2) which contains local weights. The unweighted fuzzy supermatrix is too large, hence only part of matrix is shown in Table 5. The dashed lines indicate the local weights shown in Table 4.

The components of the unweighted supermatrix are multiplied by the corresponding cluster weights (as shown in Table 6) to obtain the weighted fuzzy supermatrix. Then, the triangular fuzzy numbers in weighted fuzzy supermatrix are converted to crisp value using the CFCS method (as shown in Table 7) and normalized to obtain a limit matrix.

The normalized weighted supermatrix is multiplied by itself as long as all of its columns become equal to get limit matrix. Therefore, by calculating the limit matrix, the weights of strategies and the scores of watersheds are obtained. The results of limit matrix based on *DM1* judgment is shown in Table 8.

The above procedures have been done based on different decision-makers' judgments and the final scores of alternatives and strategies are shown in Figs. 3 and 4, respectively. As it can be seen, the watershed scores and the weights of strategies are changed based on different decision-makers' judgments. Therefore, a robust model is needed to aggregate the results by considering the decision-makers' weights and their results.

Table 10 The fuzzy relative priority matrix

	DM1	DM2	DM3	DM4	DM5	DM6
A1	(9,10,10)	(7,9,10)	(9,10,10)	(5,7,9)	(9,10,10)	(3,5,7)
A2	(0,1,3)	(0,1,3)	(0,1,3)	(0,0,1)	(0,0,1)	(1,3,5)
A3	(7,9,10)	(1,3,5)	(0,1,3)	(1,3,5)	(0,1,3)	(3,5,7)
A4	(1,3,5)	(1,3,5)	(1,3,5)	(0,0,1)	(1,3,5)	(0,1,3)
A5	(3,5,7)	(5,7,9)	(7,9,10)	(7,9,10)	(3,5,7)	(7,9,10)

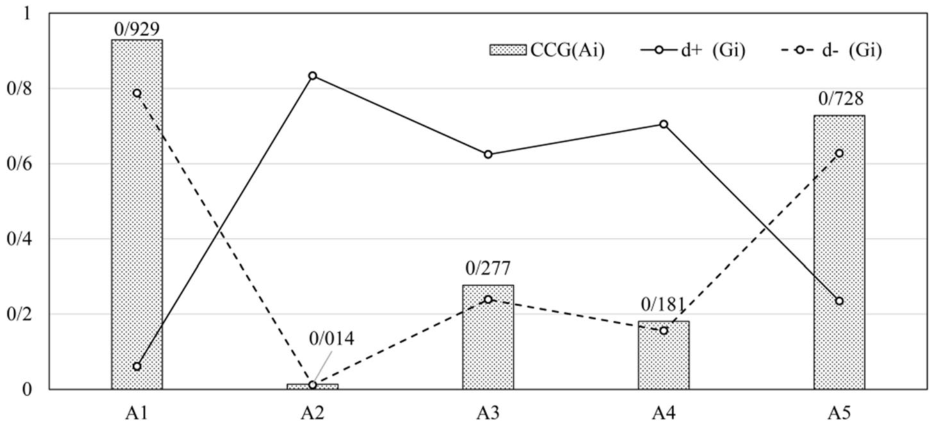

Fig. 5 The Euclidean distance d^+_{Gi}, d^-_{Gi} and the closeness coefficient ($CC_G(A_i)$) of alternatives

3.3 Fuzzy TOPSIS Method and Final Priorities

For aggregating group decision making results, it is required to calculate the weights of each decision-maker. To this end, Shannon's entropy method is used. The decision-maker weights are shown in Table 9.

The scores of alternatives obtained by each decision maker opinion (Fig. 3) are converted to a triangular fuzzy number (based on Table 2) to construct the fuzzy relative priority matrix as illustrated in Table 10.

By incorporating the weights of decision-makers (Table 9), the weighted fuzzy relative priority matrix is obtained. Then, by calculating the Euclidean distance of each alternative from positive (d^+_{Gi}) and negative (d^-_{Gi}) ideal solution, the closeness coefficient (CC_G) is calculated (Fig. 5). The alternative with the highest closeness coefficient ranks in the first position. A_1 (Urmia Lake) is the most preferred alternative for the implementation of watershed development strategies. Also, A_5 (Zayanderood) is ranked as a second watershed and Atrak is in the last ranking.

On the other hand, the priorities of development strategies determined by each decision maker are used to construct the relative priority matrix. Then, the Euclidean distance of each strategy from positive (d+) and negative (d-) ideal solution (as shown in Fig. 6) is determined

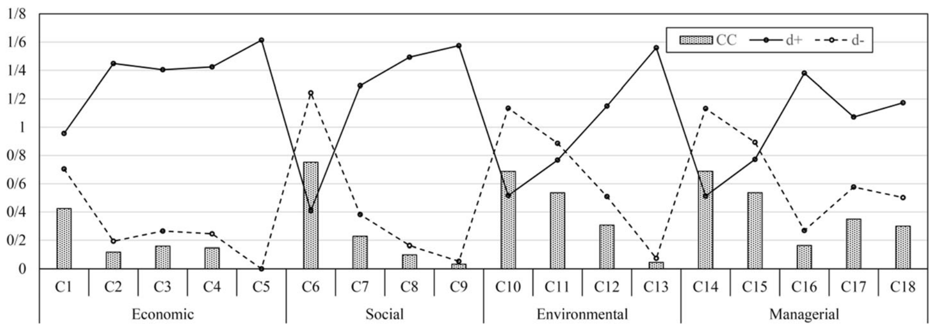

Fig. 6 The Euclidean distance d^+, d^- and the closeness coefficient (CC) of development strategies

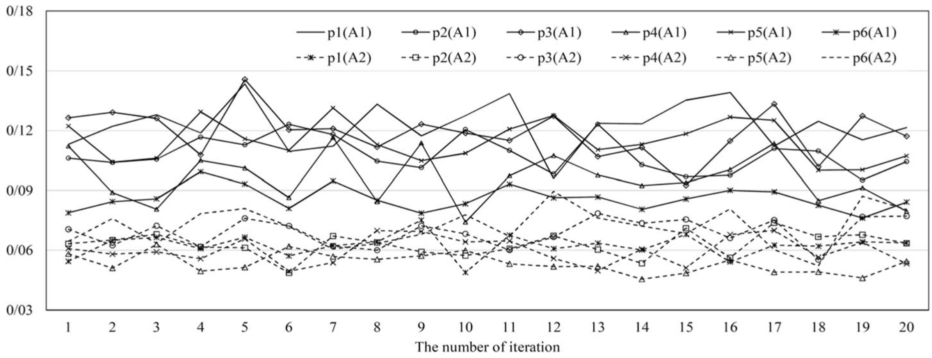

Fig. 7 Initial data for the relative priority matrix in fuzzy TOPSIS method

to achieve the final ranking. The value of the closeness coefficient (CC) in Fig. 6 indicates the final scores of development strategies.

The group decision making result indicates that *C1* (development of stakeholder participation in planning and implementation of water resources), *C6* (allocation of high quality water resources for drinking), *C10* (conservation of water resources) and *C14* (implementation of integrated water resources management) are ranked as important strategies in economic, social, environmental and managerial clusters, respectively. Besides, the average priorities of strategies in each cluster illustrate that the managerial and economic clusters are ranked in the first and last positions, respectively.

3.4 Sensitivity Analysis

One of the significant issues in MADM models is that the input data are unstable and changeable. Also, when ranking alternatives have accomplished, the sensitivity analysis can effectively contribute to make accurate decisions. Sensitivity analysis is a process of changing inputs and evaluating the final results. In this paper, the Monte Carlo method is used to generate initial data for elements of the relative priority matrix ($p^k(A_i)$) and decision-makers' weights (w_k). For this reason, 20 values of each element $p^k(A_i)$ and w_k have generated with a standard deviation of 10% of the average value of each element. Figure 7 shows some of the initial data for constructing the relative priority matrix in the fuzzy TOPSIS method. Also, decision-makers' weights are shown in Fig. 8. Then, by using the fuzzy TOPSIS method, the

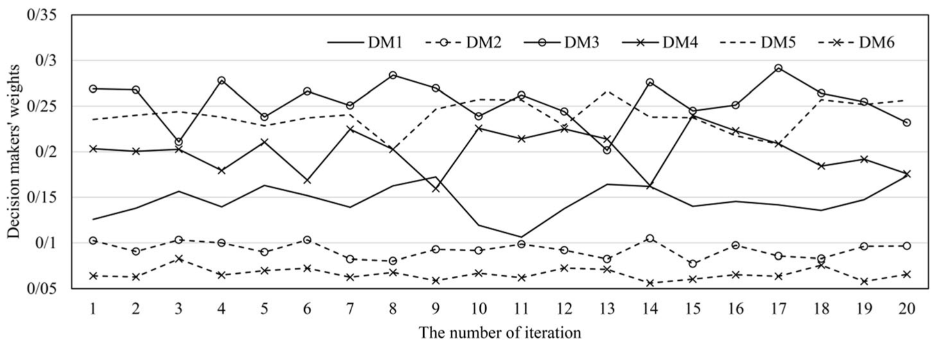

Fig. 8 Decision maker's weights in the fuzzy TOPSIS method

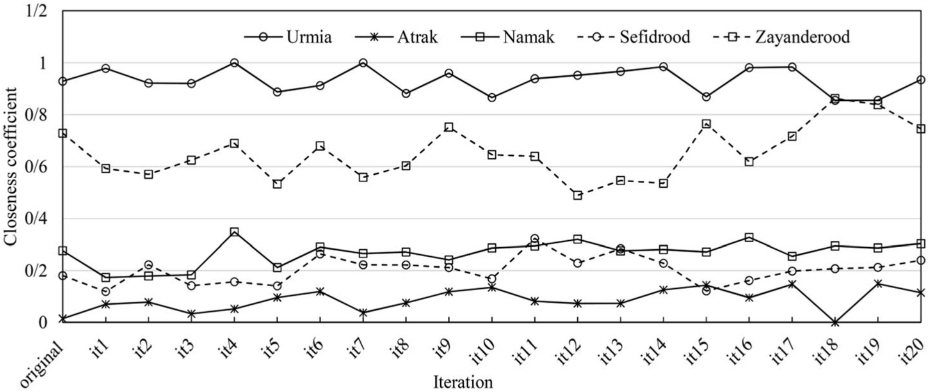

Fig. 9 Final scores of alternatives by the fuzzy TOPSIS method

closeness coefficient is calculated for each alternative to determine the final ranking. Figure 9 shows the final ranking by changing the initial data.

Referring to the results of the sensitivity analysis, it can be seen that in all of iterations diagrams, with the variation in initial data, Urmia and Atrak are the most and least preferred watersheds, respectively. In *it18* and *it19*, the scores of Urmia and Zayanderood are the same. In most iterations, Namak Lake has introduced a higher score than Sefidrood. In *it2* and *it12*, Sefidrood is ranked in third position instead of Namak Lake.

4 Conclusion

In this paper, a new hybrid multiple attribute decision-making method has developed for evaluating watersheds in a group decision-making environment. The contributions of the proposed watershed management assessment framework are: (1) it provides a comprehensive framework combines ISM-FANP-FTOPSIS for evaluating watershed management problem that could be used as an effective ranking method in various management fields, (2) it obtains a complex relations among decision elements using a mathematical process through ISM method, (3) it develops fuzzy TOPSIS and Shannon's entropy method to obtain the weights of decision-makers and aggregate group decision making results (4) it considers fuzzy arithmetic to overcome uncertainty and (5) it utilizes Monte Carlo method for sensitivity analysis to make accurate decision. The proposed method is applied to evaluating five watersheds by considering different development strategies. According to the results, Urmia Lake (A_1) is the most preferred watershed. Also, Atrak (A_2) has ranked last. This study can particularly useful as a guideline to the senior managers and decision-makers' teams to rank watersheds for effective implementation of watershed development planning and strategies. More importantly, the proposed hybrid algorithm applies to other management fields.

Acknowledgements The authors are grateful to Iran National Science Foundation (INSF) for supporting this project [grant number 92028376].

Compliance with Ethical Standards

Conflict of Interest None.

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