Fuzzy analytic hierarchy process approach in drought management: case study of Gorganrood basin, Iran

Seyed-Mohammad Hosseini-Moghari, Shahab Araghinejad and Ali Azarnivand

ABSTRACT

The current research attempts to address three main issues. First, due to the fact that it is difficult to employ a unique drought policy for the whole basin with different land uses, what is the most pragmatic approach to handle this issue? The second issue concerns development of a framework to consider both short-term and long-term strategies. Finally, the last issue is attributed to alleviating uncertainty in drought mitigation problems that must be addressed as a multiple criteria problem rather than a single criterion issue. To address the aforementioned issues, land use categorizing, applying risk management and crisis management, and employment of fuzzy analytic hierarchy process (FAHP) were considered, respectively. It should be noted that the study was associated with qualitative criteria, subjectivity, uncertainty, and synthesizing the group judgments; however, FAHP performed as a practical tool for decision-making. Raising public awareness for both civil and agricultural sectors stood superior to other strategies with defuzzified scores of 0.331 and 0.360, which are respectively 1.7 and 1.85 times larger than scores of the lowest ranked strategies in their categories. For the environmental sector, applying drought alert systems with a score of 0.507 outperformed the other risk management practices.

Key words | drought management, fuzzy analytic hierarchy process, group decision-making, land use, uncertainty

Seyed-Mohammad Hosseini-Moghari
(corresponding author)
Shahab Araghinejad
Ali Azarnivand
Department of Irrigation & Reclamation Engineering, Faculty of Agricultural Engineering & Technology,
College of Agriculture & Natural Resources, University of Tehran,
Karaj,
Iran
E-mail: *Hosseini_sm@ut.ac.ir*

INTRODUCTION

Drought hazard practices are generally divided into two groups, crisis management and risk management. Crisis management involves actions which are taken during the drought period with no prior planning (Iglesias *et al.* 2009). Most of the developing countries adopt crisis management practices, and allocate their financial and human resources to alleviate hazardous impacts of drought. Yet, due to imprecise coordination between strategies, lack of long-term vision statement, and low participation of the local stakeholders (Wilhite 1991), these responses sometimes lead to ineffective, poorly coordinated, and untimely initiatives by individuals or policy-makers (Knutson *et al.* 1998). On the other hand, throughout the risk management framework, 'a proactive approach is taken well in advance of drought so that mitigation can reduce drought impacts, and so relief recovery decisions are made in a timely, coordinated, and effective manner' (Knutson *et al.* 1998). Risk management practices, because of having a long-term vision statement, would be more effective than crisis management measures. However, because risk management strategies are time-consuming, crisis management should be taken into account simultaneously.

Although comprehensive studies have not been done to investigate the complex effects of drought on different

doi: 10.2166/aqua.2017.099

scales, evidence demonstrates that drought effects are increasing in two aspects of extent and complexity (Wilhite & Pulwarty 2005). Multidimensionality of the effects associated with drought events (Adger 1999; Mishra & Singh 2011) along with inherent multi-objectivity of water resources projects, makes it difficult for a single decision-maker to consider all relevant factors of a decision-making problem (Maier *et al.* 2014; Giuliani *et al.* 2015; Bozorg-Haddad *et al.* 2016b; Chitsaz & Azarnivand 2016). Hence, many researchers have been motivated to apply group/multi-expert decision-making techniques to facilitate interactive dialogue between stakeholders and policy-makers (Mohammadpour *et al.* 2014). Multi-criteria group decision-making (MCGDM) requires a group of experts who provide their judgments over a set of alternatives on the basis of a set of criteria (Sun & Ma 2015). Multi-criteria decision-making (MCDM) has been used in many fields, such as water privatization (Choi & Park 2001), agricultural production (Strassert & Prato 2002), water management (Srdjevic *et al.* 2004), drinking water quality (Chowdhury *et al.* 2007), socio-economic assessment (Prasad *et al.* 2007), risk assessment (Sargaonkar *et al.* 2010), site selection (Yasser *et al.* 2013), pollution controlling (Jing *et al.* 2013a, 2013b), spatial decision-making (Radmehr & Araghinejad 2014), groundwater potential mapping (Rahmati *et al.* 2014), water supply (Banihabib *et al.* 2016), erosion management (Chitsaz & Malekian 2016), natural disaster risk mitigation (Azarnivand & Malekian 2016), and conflict resolution (Bozorg-Haddad *et al.* 2016a).

The evaluation process of complex group decision-making problems is associated with uncertainty, ambiguity, and subjectivity. To address these issues, the analytic hierarchy process (AHP) not only provides a mechanism for checking the consistency of the results, but also can accommodate both tangible and intangible qualitative criteria, and individual and shared values in the group decision-making process (Dyer & Forman 1992). However, the inherent uncertainty and ambiguity associated with respondents' judgments are not fully addressed by the conventional AHP (Yang & Chen 2004; Kubler *et al.* 2016). Furthermore, water resources management in Iran is plagued by a shortage of sufficient and reliable quantitative data (Motevallian *et al.* 2014). Thus, it is crucial to provide a robust context to analyze the intangible qualitative criteria properly. As a result, fuzzy set theory, developed by Zadeh (1965), has been merged with the AHP to deal with the uncertainty. Recently, many studies have been conducted by fuzzy AHP fuzzy analytic hierarchy process (FAHP) in various aspects of water resources management, such as project assessment (Srdjevic & Medeiros 2008), wastewater treatment assessment (Karimi *et al.* 2011), evaluating ballast water treatment technologies (Jing *et al.* 2013a, 2013b), and coastal reclamation suitability evaluation (Feng *et al.* 2014).

Proper determination of the existing drought hazard potentials plus evaluation of the available resources to deal with drought within the realm of each region would be an initial step to alleviate damage caused by drought events. Later, extraction and prioritization of the appropriate responses should be taken into account by the responsible authorities. Thus, determination of appropriate policies along with practical prioritization constitutes the major objectives of the paper. Throughout the ongoing research, different practices were prioritized for urban, rural, and natural areas of Gorganrood basin, Iran, on the basis of seven evaluation criteria. In developing countries such as Iran, the disaster management was assumed equivalent to crisis management; however, Iran's government has taken risk management into account in its recent programs. Thus, as a novel action, for the first time, both drought crisis and risk management practices for each of the three above land uses in the basin were extracted, and ranked by Buckley FAHP. The reason why FAHP was used as the proposed MCDM is rooted in its capability for mitigating uncertainty of decision-making. The current study also benefitted from engagement of local stakeholders, managers, environmental activists, engineers, and academic scholars through the process of decision-making. In the rest of this research, the study area is introduced, FAHP's formula presented, prioritization results obtained and discussed, and finally, the paper ends with a conclusion.

MATERIAL AND METHODS

Study area

Located in the north of Iran and southeast of the Caspian Sea, Gorganrood basin covers an approximate area of 10,120 km^2 (Figure 1). Agriculture is the major occupation of the inhabitants, and water demand of this sector is supplied from surface and groundwater resources. Drought and a decreasing trend of precipitation in recent years has led to a shortage of surface water resources, and subsequently, overexploitation of groundwater. Hence, a dramatic decrease has occurred in the groundwater level, discharge of wells, and water quality (Hosseini-Moghari & Araghinejad 2015). Thus, it is essential to employ appropriate drought management policies for this basin. The water consumption in the basin is practically limited to agriculture and drinking; other sectors such as industry account for a small proportion of water use.

Methodology

Extraction of criteria and policies

In the present study, since it is approximately impossible to employ a unique policy for the whole basin, Gorganrood was categorized into civil, agricultural, and environmental sectors for urban, rural, and natural land uses, respectively. The environmental sector constitutes the regions in which there is no noticeable population or agricultural activities, and mainly supplies water for other parts. To take all the involved factors into account, the AHP decomposed the problem into different levels including targets, criteria, and policies. As mentioned earlier, the policies should be divided into crisis and risk management practices. Then, the feasible policies were extracted for each sector. The policies must be environmentally sustainable, technologically feasible, economically viable, socially desirable, legally permissible, administratively achievable, and politically expedient (Mee *et al.* 2008; Elliott 2011). Finally, the evaluation criteria were identified for each sector with respect to operational circumstances of the basin, such as water supply resources (surface water, groundwater), type of water use, the amount and quality of available water in the

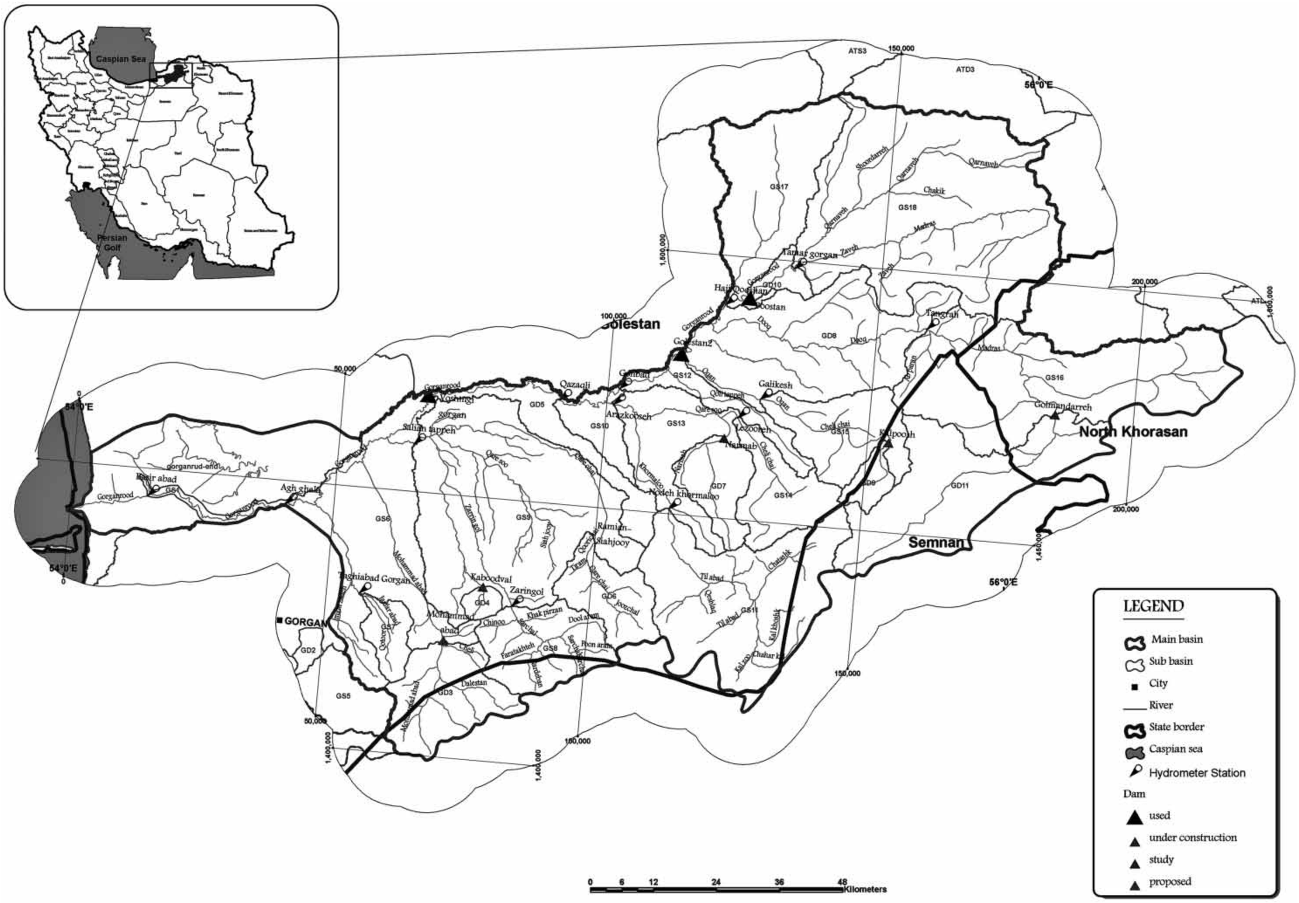

Figure 1 | Location of Gorganrood basin.

region, socio-economic considerations, etc. In this regard, a group of Iranian water resources engineering and natural resources experts as a brainstorming committee helped the authors to derive criteria and formulate strategies. Focusing on the quantity of opinions, withholding criticism, welcoming unusual ideas, and combining plus improving ideas constitute the major principles of the brainstorming procedure (Osborn 1963). The financial evaluations of strategies are based on the *Price List of Civil Engineering* (2016) reported by the Management and Planning Organization of I.R. Iran (formerly the Plan and Budget Organization). The selected criteria were as follows: C1: Economic viability; C2: Environmental sustainability; C3: Water supply reliability; C4: Execution speed; C5: Social desirability; C6: Execution simplicity; C7: Execution flexibility.

The risk and crisis management policies for the proposed targets (T) and policies (P) were determined as follows:

T1: Crisis management (civil) – P1: Mixing high-quality water with lower quality water; P2: Increasing exploitation of the groundwater resources; P3: Increasing water price; P4: Raising public awareness; P5: Regional water rationing; P6: Turning off the squares' fountains; P7: Leasing or purchasing groundwater rights.
T2: Risk management (civil) – P8: Non-conventional water use; P9: Control of leakage by pipe repairs; P10: Drought alert (warning) system; P11: Wastewater reuse.
T3: Crisis management (agriculture) – P2: Increasing exploitation of the groundwater resources; P3: Increasing water price; P4: Raising public awareness; P7: Leasing or purchasing groundwater rights; P12: Maintenance of water distribution channels; P13: Implementation of optimal cropping pattern according to the available water resources along with supportive financial aid of the government; P14: Deficit irrigation.
T4: Risk management (agriculture) – P9: Control of leakage by pipe repairs (and maintenance of channels); P10: Drought alert (warning) system; P15: Treated sewage reuse; P16: Drought insurance.
T5: Crisis management (environmental) – P12: Maintenance of water distribution channels; P17: Imposing water allocation restrictions; P18: Updating legislations and regulations related to water resources operations; P19: Using groundwater resources rather than surface water resources.
T6: Risk management (environmental) – P9: Control of leakage by pipe repairs (and maintenance of channels); P10: Drought alert (warning) system; P20: Studying the possibility and feasibility of constructing new reservoirs; P21: Artificial recharge of aquifers.

Figure 2 shows the hierarchical structure of civil, agricultural, and environmental sectors with respect to the risk and crisis management targets.

FAHP method

AHP applies pairwise comparisons to calculate weights of the criteria and policies. Decomposing the problem into different sectors made the problem easier, since the decision-makers filled smaller pairwise comparison matrices. First, the weights of the different criteria are obtained through pairwise comparisons, and then the similar process is repeated for the policies, yet with respect to satisfying the evaluation criteria. Based on the Buckley (1985) method, fuzzy weights for each fuzzy matrix are determined through a simple geometric mean operation. As stated earlier, AHP provides a mechanism to check the consistency of the preferences. In this regard, Buckley proved that, for $\tilde{A} = [\tilde{a}_{ij}]$; if $A_1 = [a_{ij}]$; is consistent; then $\tilde{A}_1 = [\tilde{a}_{ij}]$ is also consistent. Here, $\tilde{a}_{ij} = (a_{ij}, \beta_{ij}, \gamma_{ij}, \delta_{ij})$ and for all i, j; $\beta_{ij} \le \tilde{a}_{ij} \le \delta_{ij}$.

The results will be accepted if Consistency Ratio (*CR*) is less than or equal to 0.1. To check the consistency of the comparison matrix, the *CR* can be calculated through the following formula (Saaty 1980):

$$CR = \frac{\lambda_{\max} - n}{RI(n-1)} \tag{1}$$

where $\lambda_{\max}$ is the maximum eigenvalue that can be obtained from the priority matrix. Moreover, (*RI*) is a Random Index set for a randomly generated $n \times n$ matrix.

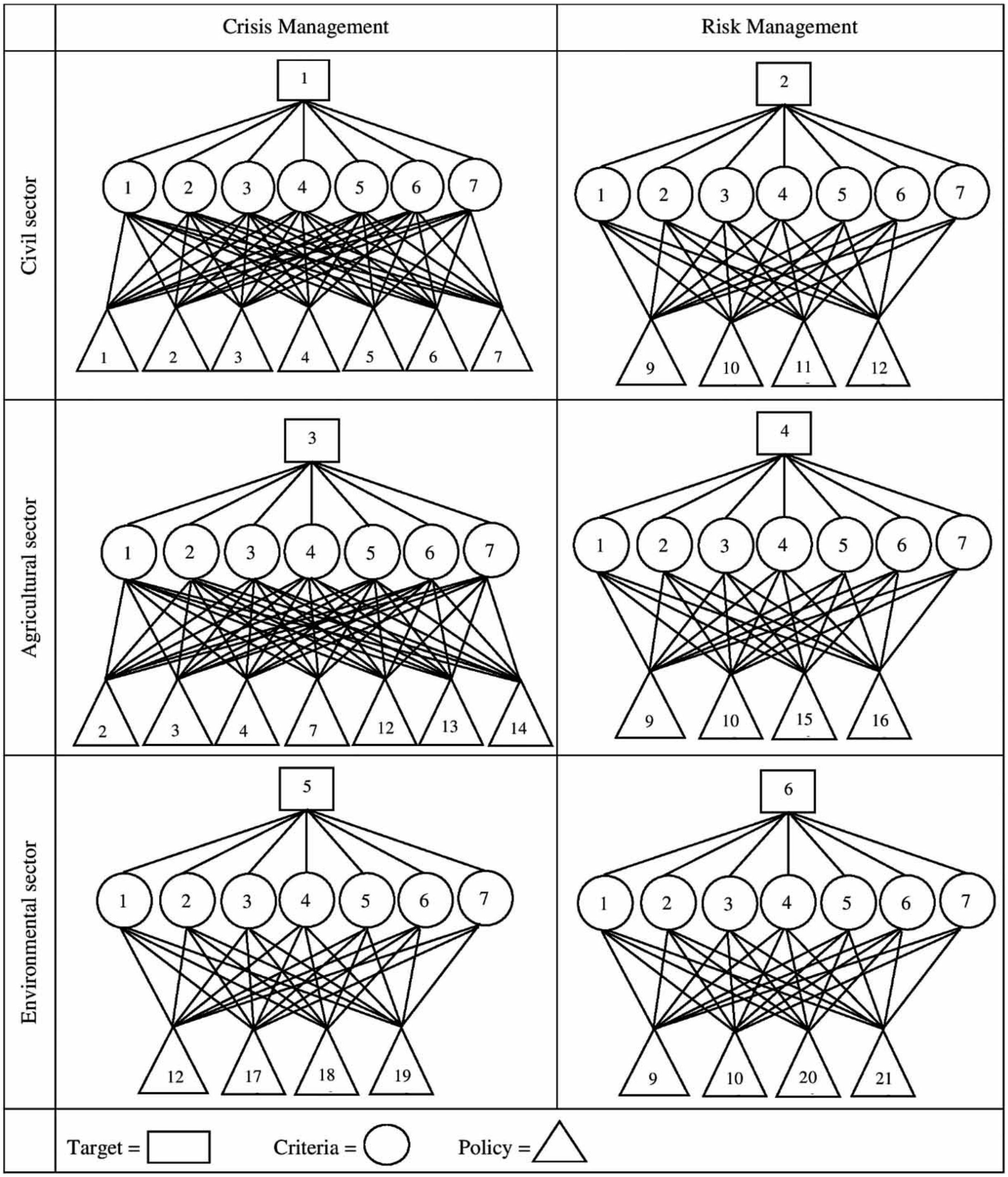

Figure 2 | Hierarchical structure related to three sectors of Gorganrood basin.

The triangular fuzzy numbers (TFNs) are presented as $\tilde{A} = (a, b, c)$, where a and c are the lower and upper bounds of the fuzzy number and b is the midpoint (Figure 3). The fuzzy numbers represent linguistic scales to obtain importance of the policies/criteria (Table 1). Each TFN is defined by its basic particulars, as follows

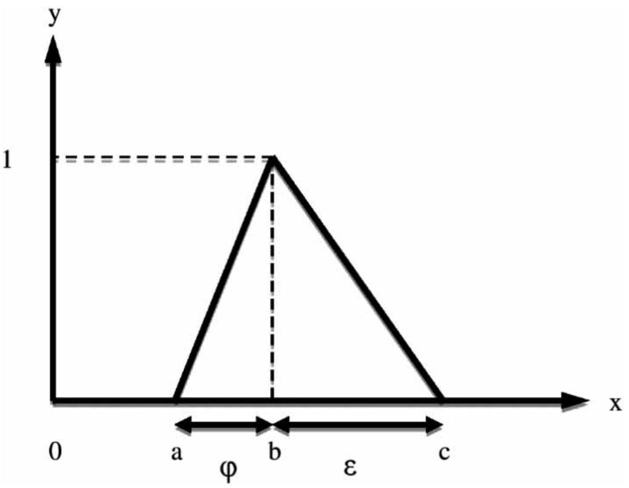

Figure 3 | A TFN $\tilde{A}$.

Table 1 | Membership functions of linguistic scale

Fuzzy number	Linguistic scales to obtain importance	Membership function ($\varphi = \varepsilon = 1$)
1	Equal importance	(1, 1, 1)
2	Between equal and weak importance	(1, 2, 3)
3	Weak importance	(2, 3, 4)
4	Between weak and strong importance	(3, 4, 5)
5	Strong importance	(4, 5, 6)
6	Between strong and very strong importance	(5, 6, 7)
7	Very strong importance	(6, 7, 8)
8	Between very strong and absolute importance	(7, 8, 9)
9	Absolute importance	(8, 9, 10)

(Chang 1996):

$$\mu_A(x) = \begin{cases} \dfrac{x-a}{b-a} & \text{for } a \le x \le b \\ \dfrac{c-x}{c-b} & \text{for } b \le x \le c \\ 0 & \text{Otherwise} \end{cases} \tag{2}$$

The criteria weights for $i, j = 1, \ldots, n$ can be calculated from the equation below:

$$\tilde{W}_i = \left[\frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} c_{ij}\right)^{\frac{1}{n}}}, \frac{\left(\prod_{j=1}^{n} b_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} b_{ij}\right)^{\frac{1}{n}}}, \frac{\left(\prod_{j=1}^{n} c_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}} \right] \tag{3}$$

Then, based on Bonissone (1982), the fuzzy utility was calculated by the following formula:

$$\tilde{U}_j = \sum_{j=1}^{n} \tilde{W}_i \cdot \tilde{r}_{ij} \tag{4}$$

where $\tilde{U}_j$, $\tilde{W}_i$ and $\tilde{r}_{ij}$ are fuzzy utility, fuzzy weights of criteria, and fuzzy weights of policies, respectively.

The next step of the prioritization process was defuzzification of fuzzy values. Considering two trapezoidal fuzzy numbers $\tilde{A}_1 = (a_1, b_1, c_1, d_1)$ and $\tilde{A}_2 = (a_2, b_2, c_2, d_2)$, then the membership function would be defined as:

$$\mu_{\tilde{U}}(x) = \begin{cases} 0 & if\, x \le (a_1 + a_2)\, or\, x \ge (d_1 + d_2) \\ 1 & if\, (b_1 + b_2) \le x \le (c_1 + c_2) \\ \alpha \epsilon [0, 1] & if\, (a_1 + a_2) \le x \le (b_1 + b_2) \\ \alpha \epsilon [0, 1] & if\, (c_1 + c_2) \le x \le (d_1 + d_2) \end{cases} \tag{5}$$

Finally, center of gravity operator was used for defuzzification of the fuzzy values as follows:

$$E_V(\tilde{U}) = \frac{\int_a^b x \cdot \mu_{\tilde{U}}(x)\, dx}{\int_a^d \mu_{\tilde{U}}(x)\, dx} \tag{6}$$

where $E_V(\tilde{U})$ is a non-fuzzy value of $\tilde{U}$ and $\mu_{\tilde{U}}(x)$ the membership function of $\tilde{U}$. The details regarding application of FAHP are presented in the Appendix (available with the online version of this paper).

RESULTS AND DISCUSSION

More than 90 participants, experts from the Regional Water Organization, farmers, environmental activists, local university scholars in such disciplines as meteorology, irrigation and drainage, hydrology, ecology, rangeland management, water resources management and engineering, and agriculture completed the questionnaires. Sixty-six validated and entirely consistent ($CR < 0.1$) questionnaires were used.

Table 2 | The aggregated fuzzy judgment matrix for the criteria

	C1			**C2**			**C3**			**C4**			**C5**			**C6**			**C7**			**Criteria weight**		
	a	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**
C1	1	1	1	0.17	0.20	0.26	0.19	0.24	0.32	0.29	0.41	0.71	1.41	1.73	2	1	2	3	1.73	2	2.24	0.05	0.08	0.13
C2	3.87	4.90	5.92	1	1	1	1	1.41	1.73	2	3	4	4.47	5.48	6.48	4	5	6	4.24	5.29	6.32	0.21	0.34	0.52
C3	3.16	4.24	5.29	0.58	0.71	1	1	1	1	1.41	2.45	3.46	3.46	4.47	5.48	3	4	5	3.87	4.90	5.92	0.17	0.27	0.44
C4	1.41	2.45	3.46	0.25	0.33	0.5	0.29	0.41	0.71	1	1	1	1.73	2	2.24	1.41	2.45	3.46	2	3.16	4.24	0.08	0.14	0.24
C5	0.71	0.58	1	0.15	0.18	0.22	0.18	0.22	0.29	0.45	0.5	0.58	1	1	1	0.58	1	1.73	1	1.41	1.73	0.04	0.06	0.10
C6	0.33	0.50	1	0.17	0.20	0.25	0.20	0.25	0.33	0.29	0.41	0.71	0.58	1	1.73	1	1	1	0.82	1.22	2	0.03	0.06	0.11
C7	0.45	0.50	0.58	0.16	0.19	0.24	0.17	0.20	0.26	0.24	0.32	0.50	0.58	0.71	1	0.5	0.82	1.22	1	1	1	0.03	0.05	0.08

The AFJM (aggregated fuzzy judgment matrix) of criteria along with their fuzzy weights is presented in Table 2. These weights were used to find out the fuzzy weights of the policies. Prior to this stage, the *CR*s (consistency ratios) of the final TFNs of policies under each criterion for each target were checked (Table 3). Table 4 reveals the evaluation parameters, defuzzified values, and ranks of the policies for each sector.

From the methodological point of view, the difference between the current study and some similar environmental crisis mitigation researches lies in the root of developing the strategies on the basis of land use and implementation horizon aspects. For instance, Azarnivand & Banihabib (2016) applied a strategic framework on the basis of internal and external strategic factors of water management, yet they ignored categorizing the priorities with consideration of land use. Sadeghravesh *et al.* (2014) prioritized five combating-desertification alternatives for central Iran via FAHP, while they did not determine any implementation vision for their ranking list. Moreover, the current research applied Fuzzy MCDM that could reduce uncertainty associated with group decision-making. Haugen & Singh (2014) and Sivakumar *et al.* (2015) neglected merging fuzzy set theory to their crisp models for overcoming the uncertainty associated with

Table 3 | Consistency ratios of aggregated policy matrices under each criterion

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Crisis management (civil)	0.04	0.02	0.02	0.08	0.09	0.04	0.04
Risk management (civil)	0.07	0.03	0.04	0.08	0.08	0.04	0.07
Crisis management (agriculture)	0.07	0.03	0.09	0.04	0.06	0.05	0.06
Risk management (agriculture)	0.09	0.03	0.09	0.05	0.09	0.08	0.05
Crisis management (environmental)	0.04	0.09	0.01	0.08	0.01	0.02	0.02
Risk management (environmental)	0.06	0.09	0.06	0.09	0.02	0.06	0.06

Table 4 | The policy scores and ranks

	a	b = c	d	L1	L2	R1	R2	Ev	Rank
Crisis management (civil)									
P1	0.048	0.117	0.291	0.015	0.054	0.039	−0.213	0.194	6
P2	0.051	0.126	0.317	0.016	0.058	0.043	−0.235	0.210	5
P3	0.041	0.107	0.289	0.015	0.050	0.043	−0.225	0.188	7
P4	0.074	0.197	0.513	0.029	0.094	0.075	−0.391	0.331	1
P5	0.050	0.128	0.337	0.018	0.060	0.048	−0.258	0.220	4
P6	0.050	0.128	0.338	0.018	0.060	0.049	−0.259	0.220	3
P7	0.078	0.196	0.480	0.027	0.092	0.063	−0.347	0.315	2
Risk management (civil)									
P8	0.099	0.269	0.735	0.041	0.128	0.113	−0.579	0.459	2
P9	0.103	0.298	0.856	0.050	0.145	0.142	−0.701	0.520	1
P10	0.072	0.199	0.561	0.032	0.095	0.092	−0.454	0.354	4
P11	0.085	0.235	0.646	0.037	0.113	0.100	−0.512	0.406	3
Crisis management (agriculture)									
P2	0.056	0.136	0.345	0.018	0.063	0.048	−0.256	0.227	4
P3	0.034	0.088	0.241	0.013	0.042	0.037	−0.190	0.157	7
P4	0.085	0.221	0.555	0.032	0.104	0.076	−0.411	0.360	1
P7	0.046	0.115	0.297	0.016	0.054	0.042	−0.224	0.195	6
P12	0.053	0.134	0.353	0.019	0.063	0.053	−0.272	0.230	3
P13	0.049	0.129	0.344	0.019	0.061	0.052	−0.268	0.224	5
P14	0.067	0.177	0.443	0.027	0.084	0.059	−0.325	0.290	2
Risk management (agriculture)									
P9	0.116	0.310	0.806	0.047	0.148	0.115	−0.611	0.506	1
P10	0.071	0.178	0.477	0.024	0.083	0.072	−0.370	0.307	4
P15	0.119	0.307	0.800	0.043	0.145	0.115	−0.608	0.502	2
P16	0.082	0.204	0.527	0.027	0.095	0.074	−0.396	0.341	3
Crisis management (environmental)									
P12	0.120	0.327	0.854	0.050	0.157	0.124	−0.650	0.533	1
P17	0.100	0.257	0.655	0.036	0.120	0.090	−0.488	0.419	2
P18	0.072	0.184	0.515	0.026	0.086	0.083	−0.415	0.327	4
P19	0.090	0.232	0.598	0.033	0.109	0.085	−0.451	0.384	3
Risk management (environmental)									
P9	0.070	0.168	0.416	0.021	0.076	0.057	−0.305	0.274	4
P10	0.135	0.329	0.791	0.043	0.151	0.101	−0.564	0.507	1
P20	0.102	0.238	0.568	0.028	0.108	0.071	−0.401	0.373	3
P21	0.113	0.265	0.644	0.032	0.121	0.083	−0.461	0.418	2

Ev, evaluation value.

group decision-making process regarding dispute resolution and green vendor selection, respectively.

According to the final results, the following remarks should be taken into consideration.

The respondents selected raising public awareness (P4) as the most significant policy for urban and rural areas. Of course, lack of dynamic connection between stakeholders, NGOs (non-governmental organizations) and the responsible authorities is a major constraint of approaching this objective. Hence, prior to beginning educational programs, it is vital to strengthen the role of NGOs and water associations in water resources planning, management, and allocation. Due to marked fluctuations in Iran's economy along with impacts of elimination of subsidies, the low rank of increasing water price in both civil and agricultural sectors is not unanticipated. Recent studies regarding water resources issues have highlighted the role of stakeholders in good governance of water (Dimadama & Zikos 2010; Lebel *et al.* 2010; Hurlbert 2012; Yazdanpanah *et al.* 2013; Nasrabadi & Shamsai 2014). The financial support for public education and awareness should be considered in the civil sector. Television and radio programs can play an important role in this area.

For civil crisis management, the second priority belonged to leasing or purchasing groundwater rights (P7), while this policy stood in the sixth rank for the agricultural target. The willingness of property owners to lease or purchase their wells is highly dependent on the availability of job opportunities. Due to a lack of new job opportunities and industrial infrastructures, the farmers were not satisfied by this policy. It is interesting to note that, in the agricultural sector, increasing exploitation of the groundwater resources (P2) stood higher than (P4). The current circumstance of groundwater resources management in Iran is a tragic story. As groundwater resources are affected by drought after surface resources, farmers used them instead of surface water reservoirs which deteriorate groundwater resources. Due to the fact that energy and water are subsidized, farmers do not show a tendency to increase the efficiency of water use (Madani 2014). Based on Foltz (2002), when the groundwater table drops, farmers dig deeper and install larger pumps. The tendency to use groundwater resources rather than surface water to compensate for water demand might seem inevitable; however, it reflects the weakness of ignoring risk management. Considering the aforementioned facts, a lack of vision statement and long-term planning throughout the crisis management framework poses new threats to the available water resources management. Crisis management might reduce the impacts of drought hazards for a short time, yet it cannot stop human greed for overuse of natural resources.

In risk management, control of leakage by pipe repairs (P9) had the highest priority among the existing policies. Considering the huge volume of water losses plus a declining trend of available water resources would be an effective measure to alleviate drought impacts. Of course, due to the fact that the score of reusing treated sewage (P15) was approximately similar to (P9), they should be implemented simultaneously. Using non-conventional (P8) and treated wastewater (P11) were the next priorities for the civil sector. Boulos *et al.* (1999) presented a framework to manage water supply during droughts within the State of California. Their framework suggested shifting away from water source development towards water supply and demand management with more emphasis on optimizing efficiency of use.

In contrast to civil and agricultural areas, (P9) was not a popular policy for the environmental sector. Owing to the fact that this sector involves natural streams, distribution networks do not have a pivotal role in water resources management. On the other hand, the highest priority belonged to the drought alert (warning) systems (P10). As mentioned earlier, this sector supplies water for the other two sectors. Hence, the impacts of drought on this sector would adversely influence socio-economic aspects of urban and rural areas. With this knowledge to hand, applying pre-disaster approaches like warning systems would outdo post-disaster measures. Based on a study which applied fuzzy drought watch evaluation, drought early warning models were suitably applied for drought management in China (Liu & Huang 2015).

During a drought crisis event, the most prominent task would be efficient utilization of the available water resources. Therefore, although the environmental sector is not highly dependent on water distribution systems, efficient performance of these systems would be significant during drought. Hence, unlike risk management, maintenance of water distribution systems (P12) outperformed others throughout the crisis management framework. Due to the fact that, in this sector, stakeholders do not directly benefit from existing water resources, water laws' enforcement was not as challenging as for civil and rural areas. Of course, this is not the sole reason for the lowest priority of (P18). In Iran, local stakeholders and the private sector do not have a pivotal role in water policy-making and, as a result, the water laws and legislations were not operated effectively.

CONCLUSIONS

The current study portrays the feasible practical long-term and short-term drought mitigation strategies for different land uses. The most striking results to emerge from the analysis of the priorities through a MCGDM framework, which can be useful for other water-limited areas around the world, were as follows.

Based on the ranking lists, although many of the criteria and policies were the same in civil, agricultural, and environmental sectors, the results were different for crisis and risk management in the three sectors. This shows that drought management varies depending on the regional characteristics. For instance, in crisis management, the lowest rank for civil and agricultural sectors belonged to increasing water prices ($EV = 0.108$), while raising public awareness outdid the others ($EV = 0.331$). Maintenance of water distribution systems and updating the legislation and regulations related to water resources operations were the most and least popular policies for the environmental sector ($EV = 0.533$ and $EV = 0.327$, respectively). Moreover, during the drought period, there is a desire for overexploitation of groundwater resources. This shows that the lack of a vision statement would lead to environmental deterioration. On the other hand, in the risk management, the lowest rank for civil and agricultural sectors belonged to drought alert systems ($EV = 0.354$ and $EV = 0.307$, respectively), while control of leakage along with reusing the treated water was superior to the others ($EV = 0.510$ and $EV = 0.526$, respectively). Installing drought alert systems and control of leakage in water distribution systems were the most and least popular policies for the environmental sector, ($EV = 0.507$ and $EV = 0.204$, respectively). Moreover, throughout risk management, the selected policies were pre-disaster oriented.

With regard to the methodological enhancement of the paper, it should be noted that the study was associated with qualitative criteria, subjectivity, uncertainty, and synthesizing the group judgments; however, Buckley FAHP performed as a practical tool for decision-making. Due to the fact that FAHP could handle these challenges properly, it is recommended for interdisciplinary decision-making problems. Decomposing the problem into three different land uses made the decision-making easier, because respondents dealt with smaller pairwise comparison matrices.

LIMITATIONS AND SUGGESTIONS FOR FUTURE WORKS

Some of the respondents were not advocates of heavily mathematical methods such as FAHP because they could not understand and apply fuzzy set theory. As a result, we had to eliminate some of the inconsistent questionnaires. It would be a helpful to develop models which not only can handle uncertainty but also be understandable for all the participants. The current research can be considered as a prerequisite for multi-objective management of drought hazards. The selected strategies should be operated optimally with consideration of minimizing the costs, optimizing water allocation, and maximizing the resiliency of operation. It would be helpful to link FAHP with optimization algorithms to provide a hybrid framework in future studies.

ACKNOWLEDGEMENTS

The authors express their gratitude to the two anonymous reviewers and the respected Associate Editor who helped us improve the quality of the paper.

REFERENCES

Adger, W. N. 1999 Social vulnerability to climate change and extremes in coastal Vietnam. *World Development* **27** (2), 249–269.

Azarnivand, A. & Banihabib, M. E. 2016 A multi-level strategic group decision making for understanding and analysis of sustainable watershed planning in response to environmental perplexities. *Group Decision and Negotiation* 1–20, doi:10.1007/s10726-016-9484-8.

Azarnivand, A. & Malekian, A. 2016 Analysis of flood risk management strategies based on a group decision making process via interval-valued intuitionistic fuzzy numbers. *Water Resources Management* **30** (6), 1903–1921.

Banihabib, M. E., Hashemi, F. & Shabestari, M. H. 2016 A framework for sustainable strategic planning of water demand and supply in arid regions. *Sustainable Development*, doi:10.1002/sd.1650.

Bonissone, P. P. 1982 A fuzzy sets based linguistic approach: theory and applications. In: *Approximate Reasoning in Decision Analysis* (M. M. Gupta & E. Sanchez, eds). Elsevier Science, North-Holland, Amsterdam, The Netherlands, pp. 329–339.

Boulos, P., Mau, R., Ringel, D. & Glaser, H. 1999 California's approach to managing water supplies during droughts. In: *Drought Management Planning in Water Supply Systems*. E. Cabrera & J. García-Serra (eds). Springer, Dordrecht, The Netherlands, pp. 322–360.

Bozorg-Haddad, O., Azarnivand, A., Hosseini-Moghari, S. & Loáiciga, H. 2016a Development of a comparative multiple criteria framework for ranking Pareto optimal solutions of a multiobjective reservoir operation problem. *Journal of Irrigation and Drainage Engineering* **142** (7), 10.1061/(ASCE) IR.1943-4774.0001028, 04016019.

Bozorg-Haddad, O., Azarnivand, A., Hosseini-Moghari, S. & Loáiciga, H. 2016b WASPAS Application and evolutionary algorithm benchmarking in optimal reservoir optimization problems. *Journal of Water Resources Planning and Management* **143** (1), 10.1061/(ASCE)WR.1943-5452.0000716, 04016070.

Buckley, J. J. 1985 Fuzzy hierarchical analysis. *Fuzzy Sets and Systems* **17** (3), 233–247, doi:10.1016/0165-0114(94)90297-6.

Chang, D. Y. 1996 Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research* **95** (3), 649–655, doi:10.1016/0377-2217(95)00300-2.

Chitsaz, N. & Azarnivand, A. 2016 Water scarcity management in arid regions based on an extended multiple criteria technique. *Water Resources Management* **31**, 233–250, doi:10.1007/s11269-016-1521-5

Chitsaz, N. & Malekian, A. 2016 Development of a risk-based multi-criteria approach for watershed prioritization with consideration of soil erosion alleviation (case study of Iran). *Environmental Earth Sciences* **75** (22), 1448.

Choi, D. J. & Park, H. 2001 Analysis of water privatization scenarios in Korea with multi-criteria decision-making techniques. *Journal of Water Supply: Research and Technology-AQUA* **50** (6), 335–352.

Chowdhury, S., Champagne, P. & Husain, T. 2007 Fuzzy risk-based decision-making approach for selection of drinking water disinfectants. *Journal of Water Supply: Research and Technology-AQUA* **56** (2), 75–93.

Dimadama, Z. & Zikos, D. 2010 Social networks as Trojan horses to challenge the dominance of existing hierarchies: knowledge and learning in the water governance of Volos, Greece. *Water Resources Management* **24** (14), 3853–3870.

Dyer, R. F. & Forman, E. H. 1992 Group decision support with the analytic hierarchy process. *Decision Support Systems* **8** (2), 99–124.

Elliott, M. 2011 Marine science and management means tackling exogenic unmanaged pressures and endogenic managed pressures – a numbered guide. *Marine Pollution Bulletin* **62** (4), 651–655, doi:10.1016/j.marpolbul.2010.12.012.

Feng, L., Zhu, X. & Su, X. 2014 Assessing coastal reclamation suitability based on a fuzzy-AHP comprehensive evaluation framework: a case study of Lianyungang, China. *Marine Pollution Bulletin* **89**, 102–111, doi:10.1016/j.marpolbul.2014.10.029.

Foltz, R. 2002 Iran's water crisis: cultural, political, and ethical dimensions. *Journal of Agricultural and Environmental Ethics* **15**, 357–380, doi:10.1023/A:1021268621490.

Giuliani, M., Castelletti, A., Pianosi, F., Mason, E. & Reed, P. 2015 Curses, tradeoffs, and scalable management: advancing evolutionary multiobjective direct policy search to improve water reservoir operations. *Journal of Water Resources Planning and Management* **142** (2), 2504015050.

Haugen, T. & Singh, A. 2014 Dispute resolution strategy selection. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* **7** (3), 10.1061/(ASCE) LA.1943-4170.0000160, 05014004.

Hosseini-Moghari, S. M. & Araghinejad, S. 2015 Monthly and seasonal drought forecasting using statistical neural networks. *Environmental Earth Sciences* **74**, 397–412, doi:10.1007/s12665-015-4047-x.

Hurlbert, M. 2012 Social learning through local water governance institutions. In: *Climate Change and the Sustainable Use of Water Resources* (W. L. Filho, ed.). Springer, Berlin, Heidelberg, Germany, pp. 685–699.

Iglesias, A., Garrote, L. & Martin-Carrasc, F. 2009 Drought risk management in Mediterranean river basins. *Integrated Environmental Assessment and Management* **5** (1), 11–16, doi:10.1897/IEAM_2008-044.1.

Jing, L., Chen, B., Zhang, B. & Peng, H. 2013a A hybrid fuzzy stochastic analytical hierarchy process (FSAHP) approach for evaluating ballast water treatment technologies. *Environmental Systems Research* **2** (1), 1–10, doi:10.1186/2193-2697-2-10.

Jing, L., Chen, B., Zhang, B., Li, P. & Zheng, J. 2013b Monte Carlo simulation-aided analytic hierarchy process approach: case study of assessing preferred non-point-source pollution control best management practices. *Journal of Environmental Engineering* **139** (5), 618–626, doi:10.1061/(ASCE)EE.1943-7870.0000673.

Karimi, A. R., Mehrdadi, N., Hashemian, S. J., Bidhendi, G. N. & Moghaddam, R. T. 2011 Selection of wastewater treatment process based on the analytical hierarchy process and fuzzy analytical hierarchy process methods. *International Journal of Environmental Science and Technology* **8** (2), 267–280, doi:10.1111/j.1752-1688.1994.tb03280.x.

Knutson, C., Hayes, M. & Phillips, T. 1998 How to reduce drought risk. Western Drought Coordination Council. http://www.drought.unl.edu/portals/0/docs/risk.pdf (accessed 26 December 2014).

Kubler, S., Robert, J., Derigent, W., Voisin, A. & Le Traon, Y. 2016 A state-of the-art survey & testbed of fuzzy AHP (FAHP) applications. *Expert Systems with Applications* **65**, 398–422.

Lebel, L., Grothmann, T. & Siebenhüner, B. 2010 The role of social learning in adaptiveness: insights from water management. *International Environmental Agreements: Politics, Law and Economics* **10**, 333–353.

Liu, Z. & Huang, W. C. 2015 Drought early warning in irrigation area by integrating surface water and groundwater. *Paddy and Water Environment* **13** (2), 145–157.

Madani, K. 2014 Water management in Iran: what is causing the looming crisis. *Journal of Environmental Studies and Science* **4** (4), 315–328, doi:10.1007/s13412-014-0182-z.

Maier, H. R., Kapelan, Z., Kasprzyk, J., Kollat, J., Matott, L. S., Cunha, M. C., Dandy, G. C., Gibbs, M. S., Keedwell, E., Marchi, A. & Ostfeld, A. 2014 Evolutionary algorithms and other metaheuristics in water resources: current status, research challenges and future directions. *Environmental Modelling and Software* **62** (1), 271–299.

Mee, L. D., Jefferson, R. L., Laffoley, D. D. A. & Elliott, M. 2008 How good is good? Human values and Europe's proposed marine strategy directive. *Marine Pollution Bulletin* **56** (2), 187–204, doi:10.1016/j.marpolbul.2007.09.038.

Mishra, A. K. & Singh, V. P. 2011 Drought modeling – a review. *Journal of Hydrology* **403** (1), 157–175, doi:10.1016/j.jhydrol.2011.03.049.

Mohammadpour, O., Hassanzadeh, Y., Khodadadi, A. & Saghafian, B. 2014 Selecting the best flood flow frequency model using multi-criteria group decision-making. *Water Resources Management* **28** (12), 3957–3974, doi:10.1007/s11269-014-0720-1.

Motevallian, S. S., Tabesh, M. & Roozbahani, A. 2014 Sustainability assessment of urban water systems: a case study. *Proceedings of the Institution of Civil Engineers-Engineering Sustainability* **167** (4), 157–164.

Nasrabadi, A. T. & Shamsai, A. 2014 Participatory developing strategies for water management in South Khorasan province, Iran. *Water Resources* **41** (6), 792–799.

Osborn, A. F. 1963 *Applied Imagination: Principles and Procedures of Creative Problem Solving*. Scribner, New York, p. 417.

Prasad, K., Strzepek, K. & van Koppen, B. 2007 An approach to assessing socioeconomic implications of water management alternatives. *Water Policy* **9** (2), 131–147, doi:10.2166/wp.2007.005.

Price List of Civil Engineering 2016 Technical note. Management and Planning Organization of I.R.IRAN [formerly Plan and Budget Organization (PBO)] (in Persian).

Radmehr, A. & Araghinejad, S. 2014 Developing strategies for urban flood management of Tehran City using SMCDM and ANN. *Journal of Computing in Civil Engineering* **28** (6), 05014006, doi:10.1061/(ASCE)CP.1943-5487.0000360.

Rahmati, O., Samani, A. N., Mahdavi, M., Pourghasemi, H. R. & Zeinivand, H. 2014 Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS. *Arabian Journal of Geosciences* **8** (9), 7059–7071.

Saaty, T. L. 1980 *The Analytic Hierarchy Process*. McGraw-Hill International, New York, NY, USA.

Sadeghravesh, M. H., Khosravi, H. & Ghasemian, S. 2014 Application of fuzzy analytical hierarchy process for assessment of combating-desertification alternatives in central Iran. *Natural Hazards* **75** (1), 653–667, doi:10.1007/s11069-014-1345-7.

Sargaonkar, A., Nema, S., Gupta, A. & Sengupta, A. 2010 Risk assessment study for water supply network using GIS. *Journal of Water Supply: Research and Technology-AQUA* **59** (5), 355–360.

Sivakumar, R., Kannan, D. & Murugesan, P. 2015 Green vendor evaluation and selection using AHP and Taguchi loss functions in production outsourcing in mining industry. *Resources Policy* **46** (1), 64–75.

Srdjevic, B. & Medeiros, Y. D. P. 2008 Fuzzy AHP assessment of water management plans. *Water Resources Management* **22** (7), 877–894, doi:10.1007/s11269-007-9197-5.

Srdjevic, B., Medeiros, Y. D. P. & Faria, A. S. 2004 An objective multi-criteria evaluation of water management scenarios. *Water Resources Management* **18** (1), 35–54, doi:10.1023/B:WARM.0000015348.88832.52.

Strassert, G. & Prato, T. 2002 Selecting farming systems using a new multiple criteria decision model: the balancing and ranking method. *Ecological Economics* **40** (2), 269–277, doi:10.1016/S0921-8009(02)00002-2.

Sun, B. & Ma, W. 2015 An approach to consensus measurement of linguistic preference relations in multi-attribute group decision making and application. *Omega* **51**, 83–92, doi:10.1016/j.omega.2014.09.006.

Wilhite, D. A. 1991 Drought planning: a process for state government. *Water Resources Bulletin* **27** (1), 29–38, doi:10.1111/j.1752-1688.1991.tb03110.x.

Wilhite, D. A. & Pulwarty, R. S. 2005 Drought and water crises: lessons learned and the road ahead. In: *Drought and Water Crises: Science, Technology, and Management Issues* (D. A. Wilhite, ed.). Taylor and Francis, Boca Raton, FL, USA, pp. 389–398.

Yang, C. C. & Chen, B. S. 2004 Key quality performance evaluation using fuzzy AHP. *Journal of the Chinese Institute of Industrial Engineers* **21** (6), 543–550, doi:10.1080/10170660409509433.

Yasser, M., Jahangir, K. & Mohmmad, A. 2013 Earth dam site selection using the analytic hierarchy process (AHP): a case study in the west of Iran. *Arabian Journal of Geosciences* **6** (9), 3417–3426.

Yazdanpanah, M., Hayati, D., Zamani, G. H., Karbalaee, F. & Hochrainer-Stigler, S. 2013 Water management from tradition to second modernity: an analysis of the water crisis in Iran. *Environment, Development and Sustainability* **15** (6), 1605–1621.

Zadeh, L. A. 1965 Fuzzy sets. *Information and Control* **8** (3), 338–353, doi:10.1016/S0019-9958(65)90241-X.

First received 3 September 2016; accepted in revised form 9 January 2017. Available online 3 March 2017