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Application of fuzzy analytical hierarchy process for assessment of combating-desertification alternatives in central Iran

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Abstract No method exists to increase the efficiency of controlling projects and reclamation of disturbed lands and avoid investment wasting, considering different criteria and alternatives and presenting optimal alternatives based on systematic and group perspectives in combating desertification. Recent proposed alternatives are usually non-systematic and non-comprehensive according to a scientific view. There is no record of application of systematic models such as multiple attribute decision-making in combating desertification. Therefore, in the present research, a fuzzy analytical hierarchy process (FAHP) method has been used to offer optimal alternatives challenging desertification. In the present study, the opinions of experts about alternatives and criteria have been assessed using the Delphi method and pairwise comparison. Then, the final priorities of the alternatives were obtained by a fuzzy decision matrix and the FAHP model. The model's ability in offering alternatives to combat desertification was assessed in the Khezr Abad region, Yazd province. Based on the obtained results, the alternative of groundwater harvesting modification with weighted average of 93 % was determined as the optimum alternative in the study area; other alternatives had no effective effect in control of desertification.

Keywords Combating desertification · Fuzzy analyses hierarchy process · Multi-criteria decision-making · Pairwise comparison

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1 Introduction

Given the importance of desertification and the complications of this phenomenon, caused by the interactions of different and numerous variables over time, it is necessary to consider optimal alternatives to prevent desertification or rehabilitate salt deserts and improve degraded lands. As losses of limited capital are prevented, the efficiency of control and rehabilitation projects is enhanced.

Studying research resources has shown that proposed alternatives to combat desertification are superficial; there is no precedent in application of systematic methods.

The only study that has applied a multi-criteria decision method to problems related to desert area management was performed by Sadeghi Ravesh et al. (2010). Therefore, methods which present optimal solutions based on strong logic and principles, while also providing a theoretical basis, remain important. Multi-criteria decision-making models including AHP can formulate the problem in hierarchical form. These models also provide the possibility of using various quantitative and qualitative criteria in the presentation of proposed alternatives. On the other hand, various options interfere in decision-making, since they are sensitive to changing factors in the future (Sadeghi Ravesh et al. 2010).

The Delphi method, first introduced in 1950s by Olaf Helmer and Norman Dalaki, is used to assess comments and work towards consensus on the occurrence or non-occurrence of events in the future. The intention of the Delphi method, as it was originally conceived, was to forecast long-range trends related to the military potential of future science and technology, and the effects of such trends on political issues (Gordon 1994; Linstone and Turoff 1975). Its main object is to obtain the most reliable consensus of opinion among expert groups. It attempts to achieve this through a series of intensive questionnaires interspersed with controlled feedback (Dalkey and Helmer 1963). The Delphi method was created from the viewpoint of a Soviet[1] strategic planner with three special characteristics, including neutral responses to the questionnaire, frequency of repetition of and feedback, and statistical analyses of the answers to the questions as a group (Somerville 2007; Azar and Faraj 2003; Asgharpour 1992). In addition, it was founded on the basis of pairwise comparisons to facilitate judgements and calculations. They use systematic group participation in choosing alternatives formed from a strong theatrical basis established on axioms (Bergamp 1995; Ghodsi pour 2002). Also, real phenomena are always fuzzy, incorrect and ambiguous, and when there is a need to comply with human behaviour (decision processes), fuzzy logic is closer to human behaviour (Azar and Faraj 2003; Meixner 2009). Therefore, in the present study, a model of fuzzy analytical hierarchy process (FAHP) has been used to achieve the goal of providing optimal alternatives for combating desertification in the framework of multi-criteria decision-making models. The FAHP method was used for first time by Laarhoven and Pedrycz in 1983, based on the logarithmic least-square method (Laarhoven and Pedrycz 1983; Zhu et al. 1999; Azar and Faraj 2003). Because of the complex calculations, the FAHP method is not used anymore.

Chang presented an extent analytical method (EAM) that uses triangular fuzzy numbers (Chang 1996; Zhu et al. 1999). Because of its strong and reasonable logic, the FAHP method was developed in various scientific areas. Of note are the following cases: the assessment of water management plans (Srdjevic and Medeiros 2008), critical decisions in new product development (Buyukozkan and Feyzioglu 2004), flexible industrial systems (Chutima and Suwanfuji 1998), safety management in production (Dagdeviren and Yuksel 2008), selection of resource-planning systems (Cebeci 2009), evaluation of optimal factors

[1] An optimal US industrial target system.

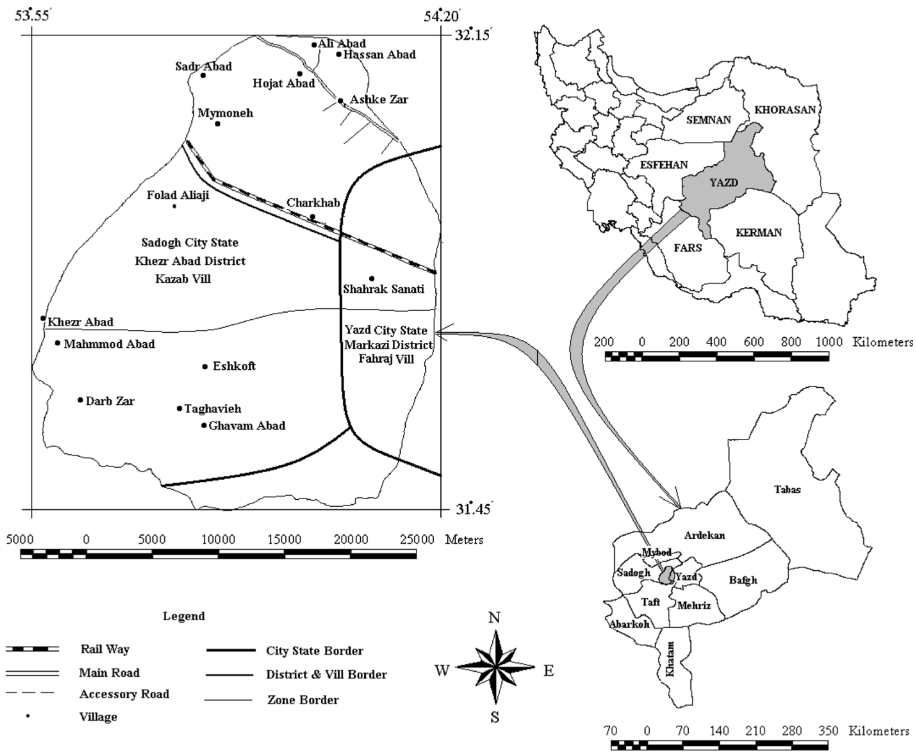

Fig. 1 Location of the study area

in electronic commerce (Kong and Liu 2005), weapon selection (Dagdeviren et al. 2009) and energy resources assessment (Meixner 2009).

The Khezr Abad region in Yazd province, central Iran, was considered for optimal determination of alternatives to combat desertification. The study area is located nearly 10 km west of Yazd. The region extends from 53°55′ to 54°20′ East in longitude and from 31°45′ to 32°15′ North in latitude, covering an area of about 78,180 ha (Fig. 1). The climate of the region is cold and arid, based on the Amberje climate classification method. About 12,930 ha (16 %) of the region is hilly, a sand-dune area,[2] which is a part of the Ashkezar Great Erg,[3] located in the northern part of the study area. About 9,022 ha (12 %) of the area consists of bare lands, clay plain and desert pavement[4] (Sadeghi Ravesh 2008; Kazemi Nejad 1996). About 1,995 ha (26.5 %) of all the agricultural land in the region consists of degraded or abounded lands with human activities such as traditional irrigation and natural processes like wind erosion and dust. The study area shows an absolutely typical condition of desertification, so effective solutions and optimal means of combating desertification must be pursued.

[2] An isolated hill, knob, ridge, outcrop or small mountain.

[3] An erg (also sand sea or dune sea, or sand sheet if it lacks dunes) is a broad, flat area of desert covered with wind-swept sand.

[4] A desert surface covered with closely packed, interlocking angular or rounded rock fragments of pebble and cobble size.

Therefore, fuzzy logic based on a hierarchical model, one of the most important and comprehensive multi-criteria decision methods, was applied to develop desertification alternatives. The structure of the model was formed on three levels: goals, criteria and alternatives.

2 Methodology

2.1 Criteria selection and alternatives to establish hierarchical decision structure

Due to the complexity of the desertification process, resulting from various factors, various criteria and alternatives have been stated by experts in every area. To establish a hierarchical structure to reduce comparisons' incompatibility, factors at any level should be 7 $\pm$ 2 (Saaty 1980). Therefore, the Delphi method was used to identify important and preferred criteria alternatives regarding the group, and to establish a hierarchical structure (Saaty 1995).

The Delphi method is appropriate when the researcher seeks a judgement of participants who have knowledge of a particular topic. With the Delphi method, participants are able to present and rationalize their opinions about the topic being researched. They also have the opportunity to consider other opinions, reconsider their own opinions and assess the relative importance of each presented opinion. To ensure soundness of data, researchers should pay particular attention to panel selection and motivation, questionnaire construction, process management and the method used to aggregate panellists' opinions (Somerville 2007).

Towards these aims, first of all, a questionnaire was designed based on the literature, and the nine-point Satty scale, from one (least important) to nine (most important), was used to measure the relative importance of criteria and the priorities of alternatives for combating desertification (Table 1). Then, a questionnaire was distributed among experts familiar with the study area. After that, arithmetical means were used to calculate the mean of the obtained results. Then, the primary statistical community was asked to apply their final changes based on deviations of their primary values from the average. Finally, mean values were calculated. In this case, if the mean value was <7 ($\overline{X} < 7$), related criteria and alternatives were removed, and if the mean value was more than or equal to 7 ($\overline{X} \geq 7$), related criteria and alternatives were used to design a hierarchical decision structure on three levels: goals, criteria and alternatives (Tables 4, 5, 6; Fig. 2) (Azar and Rajabzadeh 2002; Sung 2001).

Table 1 Importance and priority degree of nine-point Satty scale

Score	Importance degree	Priority degree
1	Non-importance	Equal
2	Very low	Equal-moderately
3	Low	Moderately
4	Relatively low	Moderately–strongly
5	Medium	Strongly
6	Relatively high	Strongly–very strongly
7	High	Very strongly
8	Very high	Very strongly–extremely
9	Excellent	Extremely

Table 2 Fuzzy pairwise-comparison matrix

M_{11}^{K}	M_{12}^{K}	$\cdots$	$M_{1n_{K-1}}^{K}$
M_{21}^{K}	M_{22}^{K}	$\cdots$	$M_{2n_{K-1}}^{K}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$M_{n_K 1}^{K}$	$M_{n_K 2}^{K}$	$\cdots$	$M_{n_K n_{K-1}}^{K}$

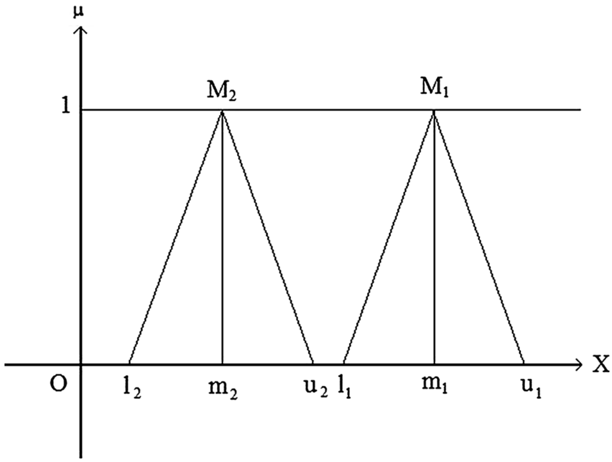

Fig. 2 Two triangular fuzzy numbers

2.2 Calculate local priority of criteria and alternatives by using the Delphi fuzzy method and establish group pairwise-comparison matrix

To achieve local priority, a second questionnaire entitled 'pairwise comparisons questionnaire' was designed using the Delphi fuzzy method. The experts were asked to conduct a pairwise comparison of the results obtained from the first questionnaire with minimum, probable and maximum (number of fuzzy triangle) (Eqs. 1 and 2; Fig. 2) on the nine-point Saaty scale (Table 1) based on the importance to the goal and priority of each criterion, respectively. Thus, a pairwise-comparison matrix about criteria importance and alternatives priority was formed by each expert based on the general form of the pairwise-comparison matrix in AHP (Table 2) (Ghodsi pour 2002).

$$\tilde{A}_{ij}^{t} = \left(l_{ij}^{t}, m_{ij}^{t}, u_{ij}^{t}\right), \quad i,j = 1,2,\ldots n_K, \quad t = 1,2\ldots \tag{1}$$

$$\tilde{A}_{ji}^{t} = \left(\frac{1}{u_{ij}^{t}, m_{ij}^{t}, l_{ij}^{t}}\right), \quad i,j = 1,2,\ldots n_K, \quad t = 1,2\ldots \tag{2}$$

In these equations, $\tilde{A}_{ij}^{t}$ fuzzy component of t experts, to pairwise comparisons of alternative priority or criteria of i to j, $\tilde{A}_{ji}^{t}$ fuzzy component of t experts, to pairwise comparisons of alternative priority or criteria of j to i, l_{ij}^{t} fuzzy minimum number of t experts, m_{ij}^{t} fuzzy possible number of t expert, u_{ij}^{t} fuzzy maximum number t experts.

Subsequently, using geometrical mean and assuming identical votes of all asked experts, the pairwise-comparison matrix of each expert and the group pairwise-comparison matrix were formed by Eq. (3):

$$M_{ij}^{K} = \frac{1}{T}\left(\tilde{A}_{ij}^{1} + \tilde{A}_{ij}^{2} + \cdots + \tilde{A}_{ij}^{T}\right) \tag{3}$$

In Eq. 3, M_{ij}^{K} fuzzy component of K group or the average of triangular fuzzy numbers, $\tilde{A}_{ij}^{t}$ fuzzy component of t experts, and T the number of triangular fuzzy numbers.

Geometrical average (M_{ij}^{K}) for all similar fuzzy components is obtained by Eq. 3 (Zare and Ahmadi Naseri 2008). After establishing a pairwise-comparison matrix of the fuzzy group, the matrix was distributed among statistical societies to finalize the experts' opinions. They were asked to apply final changes to their values according to their responses' deviations from the mean. Finally, final pairwise-comparison matrices were obtained using the geometrical mean of weights (Table 2).

2.3 Compute $\tilde{S}_K$ value or synthetic triangular fuzzy number for each row of fuzzy pairwise-comparison matrix by Eq. (4)

$$\tilde{S}_K = \sum_{j=1}^{n} M_{K_j}^{K}\left[\sum_{i=1}^{n_K}\sum_{j=1}^{n_K} M_{ij}^{K}\right]^{-1}, \quad i = 1, 2, \ldots, n_K \tag{4}$$

In Eq. 4, $\tilde{S}_K$ synthetic triangular fuzzy numbers, $\sum_{j=1}^{n} M_{K_j}^{K}$ total rows of criteria or alternatives' priorities in pairwise-comparison tables from group perspective, M_{ij}^{K} fuzzy component of K group, $\sum_{i=1}^{n_K}\sum_{j=1}^{n_K} M_{ij}^{K}$ total rows obtained from total columns of criteria or alternatives' priorities in pairwise-comparison tables, K number-of-rows matrix, i alternatives, j criteria.

2.4 Compute $\tilde{S}_K$ largeness degree for each row of group pairwise-comparison matrix by Eq. (5)

$$\begin{cases} V\left(\tilde{S}_{ij}^{K} \geq \tilde{S}_{j}^{K}\right) = 1, & m_1 \geq m_2, \quad j = 1, 2, \ldots, n_K, \quad j \neq i \\ V\left(\tilde{S}_{ij}^{K} \geq \tilde{S}_{j}^{K}\right) = \dfrac{u_1 - l_2}{(u_1 - l_2) + (m_2 - m_1)} & \text{Otherwise}, \quad j = 1, 2, \ldots, n_K, \quad j \neq i \end{cases} \tag{5}$$

In Eq. 5, $V\left(\tilde{S}_{ij}^{K} \geq \tilde{S}_{j}^{K}\right)$ largeness degree of synthetic triangular fuzzy numbers in pairwise comparison, m_1 possible fuzzy number of primary alternative or criterion, m_2 possible fuzzy number of secondary alternative or criterion, u_1 fuzzy maximum number of primary alternative or criterion, l_1 fuzzy minimum number of secondary alternative or criterion.

2.5 Compute largeness degree of each synthetic triangle fuzzy number from K other synthetic triangular fuzzy number by Eq. (6)

$$P_{ih}^{K}\left(A_{i}^{K}\right) = \min V\left(\tilde{S}_{i}^{K} \geq \tilde{S}_{j}^{K}\right), \quad i = 1, 2, \ldots, n_K \tag{6}$$

In Eq. 6, $P_{ih}^{K}\left(A_{i}^{K}\right)$ non-normal weight of t alternative or criterion from tables of K fuzzy pairwise-comparison matrix, $\min V\left(\tilde{S}_i^K \geq \tilde{S}_j^K\right)$ the minimum value of each synthetic triangular fuzzy number compared to other synthetic triangular fuzzy numbers, $\tilde{S}_i^K$ primary synthetic triangular fuzzy number, $\tilde{S}_j^K$ secondary synthetic triangular fuzzy number, A_i^K i criteria or alternative from K fuzzy pairwise matrix.

The number obtained from the process shows non-normalized weights of criteria or alternatives of pairwise-comparison matrix for criteria preference and alternatives' priorities.

2.6 Normalizing non-normalized weights of criteria and alternatives by Eq. (7) obtaining criteria preference and alternatives' priorities from group viewpoint (Eq. 8)

$$P_h^K = \frac{P_{ih}^K\left(A_i^K\right)}{\sum_{ih}^K P_{ih}^K\left(A_i^K\right)} \quad i = 1, 2, \ldots, n_K \tag{7}$$

$$P_h^K = P_{1h}^K, P_{2h}^K, \ldots, P_{n_K h}^K \tag{8}$$

In Eqs. 7 and 8, P_h^K normal weight of alternative or criterion priority from K layer to criteria with h aim from $K-1$ layer or layer at higher levels of hierarchy, $P_{ih}^K\left(A_i^K\right)$ largeness degree of i criterion or alternative from tables of K fuzzy pairwise-comparison matrix, $\sum_{i=1}^K P_{ih}^K\left(A_i^K\right)$ total largeness degree of criteria or alternatives.

This equation expresses preference or priority of each criterion and alternative from K fuzzy pairwise-comparison matrix related to the goal of higher hierarchical decision-making. Therefore, the priorities of criteria related to the goal (desertification optimal alternative) can be shown as in Eq. 9:

$$C^{K-1} = \left(C_1^{K-1}, C_2^{K-1}, \ldots, C_{n_{K-1}}^{K-1}\right) \tag{9}$$

In Eq. 9, preference (local priority) of each criterion (C) is expressed based on the goal in higher level ($K-1$), C^{K-1} preference of each criterion to goal in higher level ($K-1$).

Priority of each alternative (A) to each criterion (C) located in higher levels (K) of alternatives is presented by Eq. 10:

$$A_{ij}^K = \left(A_{1h}^K, A_{2h}^K, \ldots, A_{n_K h}^K\right)^T \tag{10}$$

A_{ij}^K priority of each alternative (A) to each criterion (C) located in higher levels (K) of alternatives.

Table 3 Decision-making matrix in FAHP

A_i^K	Criterion				P_i^K
	C_1^{K-1}	C_2^{K-1}	…	$C_{n_{K-1}}^{K-1}$	
A^1	A_{11}^K	A_{12}^K	…	$A_{1n_{K-1}}^K$	P^1
A^2	A_{21}^K	A_{22}^K	…	$A_{2n_{K-1}}^K$	P^2
⋮	⋮	⋮	⋮	⋮	⋮
A^K	$A_{n_K 1}^K$	$A_{n_K 2}^K$	…	$A_{n_K n_{K-1}}^K$	P^K

2.7 Establishment of fuzzy decision-making matrix

To determine final alternatives' weights, a fuzzy decision-making matrix (Table 3) was formed based on the decision-making matrix in AHP and according to Eqs. 9 and 10.

2.8 Synthesis of local priority of criteria preference and alternatives' priorities by using harmonic mean method (relation 11) and estimate priority coefficient of alternatives based on criteria set from group viewpoint

$$P_i^K = \sum_{j=1}^{n_{K-1}} A_{ij}^K C_j^{K-1} \tag{11}$$

In Eq. 11, P_i^K priority coefficient of alternatives based on set of criteria, C^{K-1} preference of each criterion to goal in higher level ($K - 1$), A_{ij}^K priority of each alternative (A) to each criterion (C) located in higher levels (K) of alternatives.

Therefore, the alternative that has the highest priority coefficient is selected as the best alternative and other alternatives are prioritized similarly.

3 Results and discussion

In the process of desertification alternatives assessment in the study area, the Delphi method and questionnaire were used first to identify the main criteria and alternatives among 16 criteria and the 40 combating-desertification alternatives according to the group. Tables 4, 5 and 6 shows the recommended alternatives, offering criteria and alternative priority average, respectively. Then, these were used to establish hierarchical decision-making graphs (Fig. 2) and a pairwise-comparison questionnaire (Fig. 3).

After selecting the main criteria and alternatives according to the group, the fuzzy Delphi method of group pairwise-comparison matrices was employed to determine local priority of criteria and alternatives for achieving the goal of 'offering optimal combating-desertification alternatives'. Here, to prevent prorogation speech, only two pairwise comparisons were expressed, first fuzzy pairwise-comparison matrices of criteria based on the above goal (Table 7) and secondly a group pairwise-comparison matrix of alternative priority according to criteria of time (Table 8). The matrices of alternative priority compared to other criteria were designed as in Table 8.

The value of $\tilde{S}_K$ was then calculated for each row of fuzzy pairwise-comparison matrices using a synthetic triangle fuzzy number as in Eq. 4. In the following, the results of $\tilde{S}_K$ obtained from Tables 7 and 8 are noted (Examples 1 and 2):

Example 1 The $\tilde{S}_K$ value obtained from group pairwise-comparison matrix of criteria importance according to the goal of 'offering optimal combating-desertification alternatives':

Table 4 The recommended alternatives to combat desertification

Modification, creation and development of economical-social infrastructure in marginal areas	
A_1	Reducing population growth rates
A_2	Poverty alleviation
A_3	Establishment and development of rural organizations
A_4	Increasing employment
A_5	Increasing participation of local community and supporting NGOs
A_6	Application of local forces and technology in projects (local knowledge)
A_7	Training people in utilization of new methods and use of new knowledge for optimal use of resources
A_8	Approval, promotion and implementation of laws and adaptation punishment with crime
A_9	Providing needs of local residents
A_{10}	Modification of unsustainable consumption patterns, changing and improving people's livelihood patterns
A_{11}	Considering the role of women and youth in combating desertification
A_{12}	Organization of urban areas and prevent migration
A_{13}	Coordination between responsible agencies and organizations in desertification and environmental protection
A_{14}	Raising the literacy rate
A_{15}	Development of desert ecotourism
A_{16}	Multi-utilization from desert instead of mono-utilization
A_{17}	Allocation desertification issues to the private sector
A_{18}	Prevention of unsuitable land-use changes
A_{19}	Mapping land-use planning and determination of desert and salt desert boundaries
Vegetation cover conservation	
A_{20}	Livestock grazing Control
A_{21}	Forage production and increasing economic potential of sustainable husbandry
A_{22}	Prevention of Plant cutting
A_{23}	Vegetation cover development and reclamation
A_{24}	Protection of *Haloxylon* spp.
Soil conservation	
A_{25}	Protection of gravel surfaces (Reg)
A_{26}	Prevention and reduction in heavy agricultural and industrial machineries traffics
A_{27}	Create living and non-living wind break for soil conservation
A_{28}	Improvement of soil texture
Development of sustainable agriculture	
A_{29}	Modification of crop rotation and fallow methods
A_{30}	Modification of ploughing, fertilization, spraying methods
Development and sustainable management of water resources	
A_{31}	Modification of groundwater harvesting
A_{32}	Reduction in water consumption (water optimal consumption in farms)
A_{33}	Change of irrigation patterns
A_{34}	Changing traditional irrigation systems with low efficiency to modern systems with high efficiency

Table 4 continued

A_{35}	Optimal collecting and harvesting of water resources (including rivers isolating, Qanat repairing and dredging, utilization of canals and streams and desalination of salty waters)
A_{36}	Groundwater feed
A_{37}	Construction of flood broadcast networks and the use of its alluviums
A_{38}	Creation of artificial precipitation to fed aquifers
A_{39}	Promotion of greenhouse cultivation
A_{40}	Introduction of new plant varieties, resistant to drought and dehydration stress by genetic engineering

$$\tilde{S}_2 = (2.57,\ 2.87,\ 3.20) \times (0.0346,\ 0.0302,\ 0.0256) = (0.089,\ 0.087,\ 0.082)$$

$$\tilde{S}_5 = (3.31,\ 3.60,\ 3.86) \times (0.0346,\ 0.0302,\ 0.0256) = (0.114,\ 0.109,\ 0.098)$$

$$\tilde{S}_6 = (5.01,\ 5.60\,,\ 6.32) \times (0.0346,\ 0.0302,\ 0.0256) = (0.173,\ 0.169,\ 0.162)$$

$$\tilde{S}_7 = (9.24,\ 10.72,\ 12.33) \times (0.0346,\ 0.0302,\ 0.0256) = (0.320,\ 0.324,\ 0.316)$$

$$\tilde{S}_{16} = (8.75,\ 10.29,\ 13.3) \times (0.0346,\ 0.0302,\ 0.0256) = (0.302,\ 0.310,\ 0.340)$$

Example 2 The $\tilde{S}_K$ value obtained from group pairwise-comparison matrix of criteria importance according to the criteria of time:

$$\tilde{S}_{18} = (4.4,\ 5.05,\ 5.92) \times (0.0346,\ 0.0302,\ 0.0256) = (0.204,\ 0.195,\ 0.181)$$

$$\tilde{S}_{20} = (4.26,\ 5.85,\ 9.16) \times (0.0346,\ 0.0302,\ 0.0256) = (0.198,\ 0.216,\ 0.279)$$

$$\tilde{S}_{23} = (5.62,\ 6.42,\ 7.27) \times (0.0346,\ 0.0302,\ 0.0256) = (0.261,\ 0.248,\ 0.222)$$

$$\tilde{S}_{31} = (3.8,\ 4.36,\ 5.35) \times (0.0346,\ 0.0302,\ 0.0256) = (0.176,\ 0.168,\ 0.163)$$

$$\tilde{S}_{33} = (3.46,\ 4.16,\ 5.04) \times (0.0346,\ 0.0302,\ 0.0256) = (0.161,\ 0.160,\ 0.154)$$

Now according to the obtained value of $\tilde{S}_K$ for each fuzzy group pairwise-comparison matrix, the value of each synthetic triangle fuzzy number ($\tilde{S}_K$) was compared to each other by Eq. 5, and their significance was estimated. Then, the significance of each synthetic triangle fuzzy number was estimated from synthetic triangle fuzzy numbers of $K = 4$ by Eq. 6 (Examples 3 and 4):

Example 3 Non-normalized weights of criteria preference related to goal of 'offering optimal combating-desertification alternatives:

$$\min V\left(\tilde{S}_7 \geq \tilde{S}_2,\ \tilde{S}_5,\ \tilde{S}_6,\ \tilde{S}_{16}\right) = (1,\ 1,\ 1,\ 1) = 1$$

$$\min V\left(\tilde{S}_{16} \geq \tilde{S}_2,\ \tilde{S}_5,\ \tilde{S}_6,\ \tilde{S}_7\right) = (1,\ 1,\ 1,\ 0.61) = 0.61$$

$$\min V\left(\tilde{S}_6 \geq \tilde{S}_2,\ \tilde{S}_5,\ \tilde{S}_7,\ \tilde{S}_{16}\right) = (1,\ 1,\ 4.44,\ -141) = -141$$

$$\min V\left(\tilde{S}_3 \geq \tilde{S}_2,\ \tilde{S}_6,\ \tilde{S}_7,\ \tilde{S}_{16}\right) = (1,\ 5,\ 22,\ 35.67,\ 102) = 1$$

$$\min V\left(\tilde{S}_2 \geq \tilde{S}_5,\ \tilde{S}_6,\ \tilde{S}_7,\ \tilde{S}_{16}\right) = (3.31,\ 10.47,\ 396.66,\ -67) = -67$$

Table 5 The criteria and their importance mean according to the group

Code	Criteria	Average values
C_1	Expenses–benefits	5.38
C_2	Time	7.1
C_3	Participation of local communities	5.78
C_4	Beauty of landscape	5.1
C_5	Access to the technologies and scientific methods and devices	7.1
C_6	Access to the related experts	7.53
C_7	Proportion and adaptation to the environment (sustainability)	8.15
C_8	Traditional management and local Knowledge	5.23
C_9	Government authority in combating-desertification projects	5.28
C_{10}	Oil incomes of government	5.72
C_{11}	Temporary management of projects	2.39
C_{12}	The problems resulted from innovation and method changes	2.84
C_{13}	Indolence State Administrative Systems	2.29
C_{14}	Political and social pressures	5.35
C_{15}	Emergency issues related to desertification occurrence	6.34
C_{16}	Destruction of resources, human and social damages	7.99

Example 4 Non-normalized weights of alternative priority related to the 'time' criteria:

$$\min V\left(\tilde{S}_{18} \geq \tilde{S}_{20},\ \tilde{S}_{23},\ \tilde{S}_{31},\ \tilde{S}_{33}\right) = (-4.25,\ 2.82,\ 1,\ 1) = -4.25$$
$$\min V\left(\tilde{S}_{23} \geq \tilde{S}_{18},\ \tilde{S}_{20},\ \tilde{S}_{31},\ \tilde{S}_{33}\right) = (1,\ 1,\ 1,\ 1) = 1$$
$$\min V\left(\tilde{S}_{33} \geq \tilde{S}_{18},\ \tilde{S}_{20},\ \tilde{S}_{23},\ \tilde{S}_{31}\right) = (3.13,\ -4,\ 5.35,\ 1.46) = -4$$
$$\min V\left(\tilde{S}_{20} \geq \tilde{S}_{18},\ \tilde{S}_{23},\ \tilde{S}_{31},\ \tilde{S}_{33}\right) = (1,\ 0.36,\ 1,\ 1) = 0.36$$
$$\min V\left(\tilde{S}_{31} \geq \tilde{S}_{18},\ \tilde{S}_{20},\ \tilde{S}_{23},\ \tilde{S}_{33}\right) = (-30,\ -2.69,\ -5.44,\ 1) = -30$$

Non-normalized weights were normalized by Eq. 7, and criteria preference and alternative priority from the group viewpoint were determined (Examples 5 and 6).

Example 5 Normalized weights of criteria preferred related to the goal of 'offering optimal combating-desertification alternatives'

$$P_{\tilde{S}_K} = (0.326,\ -0.00296,\ 0.686,\ -0.0048,\ -0.00296)$$

Example 6 Normalized weights of alternative priority related to 'time' criteria.

$$P_{\tilde{S}_K} = (0.115,\ -0.00976,\ -0.027,\ 0.813,\ 0.108)$$

At the end, by estimation of all normalized weights of criteria related to goal and alternatives related to each criterion, the fuzzy decision-making matrix of the optimal combating-desertification alternatives from the group viewpoint (Table 9) was formed in the framework of the decision-making matrix in FAHP (Table 3).

Table 6 The average alternative priority according to the group

Alternative	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
Average values	5	5.68	5.35	6.7	6.1	6.56	6.47	5.73	5.89	5.6
Alternative	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}
Average values	4.5	5.23	6.86	4.8	5.32	5.27	3.79	7.5	6.44	7.34
Alternative	A_{21}	A_{22}	A_{23}	A_{24}	A_{25}	A_{26}	A_{27}	A_{28}	A_{29}	A_{30}
Average values	6.6	6.46	7.56	6.76	6.45	5.57	6.86	4.66	5.42	5.1
Alternative	A_{31}	A_{32}	A_{33}	A_{34}	A_{35}	A_{36}	A_{37}	A_{38}	A_{39}	A_{40}
Average values	7.24	6.6	7.49	6.53	6.64	6.08	5.3	3.47	6.2	6

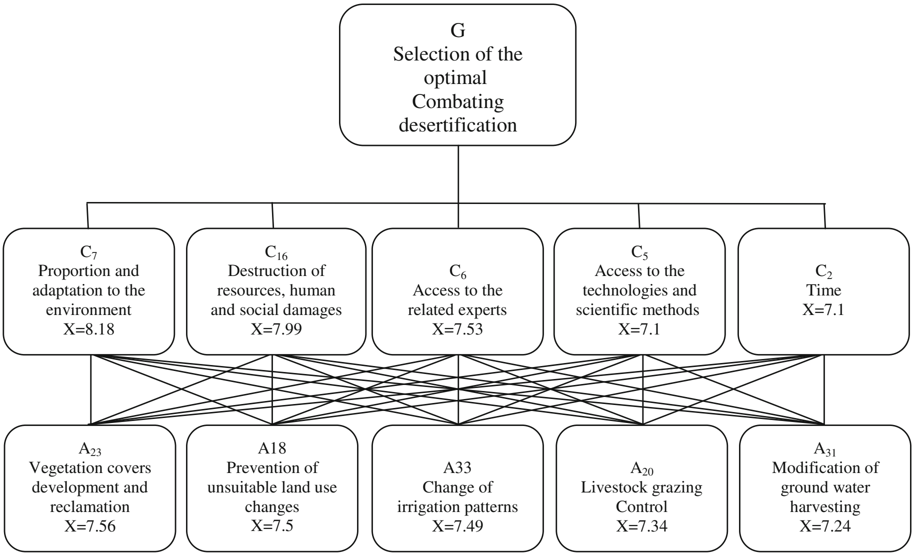

Fig. 3 Decision-making hierarchical graph to study fuzzy pairwise comparison in Khezr Abad region

Table 7 Fuzzy pairwise-comparison matrices of criteria based on goal of 'offering optimal combating-desertification alternatives'

Criteria	C_2	C_5	C_6	C_7	C_{16}	Sum
C_2	0, 0, 0	0.67, 0.76, 0.89	0.41, 0.49, 0.60	0.27, 0.3, 0.33	0.23, 0.32, 0.38	2.57, 2.87, 3.2
C_5	1.12, 1.31, 1.5	0, 0, 0	0.54, 0.57, 0.60	0.36, 0.39,041	0.29, 0.33, 0.35	3.31, 3.6, 3.86
C_6	2.56, 3.08, 4.34	1.66, 1.74, 1.86	0,0, 0	0.34, 0.39, 0.46	0.35, 0.43, 0.58	5.01, 5.6, 6.32
C_7	3.05, 3.38, 3.71	2.43, 2.55, 2.78	2.17, 2.55, 2.93	0, 0, 0	0.59, 1.24, 1.91	9.24, 10.72, 12.33
C_{16}	2.65, 3.08, 4.34	2.87, 3.07, 3.40	1.71, 2.33, 2.87	0.52, 0.81, 1.60	0, 0, 0	8.75, 10.29, 13.3

Table 8 Fuzzy pairwise-comparison matrices of alternative priority according to the criteria of time (C_2)

Alternative	A_{18}	A_{20}	A_{23}	A_{31}	A_{33}	Sum
A_{18}	0, 0, 0	1, 1.08, 1.2	0.54, 0.68, 0.95	0.78, 1.06, 1.35	1.08, 1.23, 1.42	4.4, 5.05, 5.92
A_{20}	0.83, 0.93, 1	0, 0, 0	0.72, 0.81, 0.92	0.88, 1.64, 2.24	0.83, 1.47, 4	4.26, 5.85, 9.16
A_{23}	1.05, 1.46, 1.86	1.09, 1.23, 1.38	0, 0, 0	1.30, 1.39, 1.5	1.18, 1.34, 1.53	5.62, 6.42, 7.27
A_{31}	0.74, 0.94, 1.28	0.45, 0.61, 1.14	0.67, 0.72, 0.77	0, 0, 0	0.94, 1.09, 1.16	3.8, 4.36, 5.35
A_{33}	0.7, 0.81, 0.93	0.25, 0.68, 1.2	0.65, 0.75, 0.85	0.86, 0.92, 1.06	0, 0, 0	3.46, 4.16, 5.04

After forming the fuzzy decision-making matrix in order to finally select alternatives and their priority ranking, the synthesis process was performed on the weights of the matrix by using the harmonic mean method (Eq. 11), or the mean of each normalized matrix row.

According to the results of the alternative process, modification of groundwater harvesting (A_{31}) with priority coefficient of 0.93 is the most important alternative in controlling and decreasing desertification effects and reclamation of degraded land based on criteria set in the study area.

Also the results showed that Yazd–Ardakan basin,[5] with deficit balance equal to 187×10^6 m^3, faces improper water balance. In the study, highlands and bar pediment in the southern area have less sensitivity to desertification than covered pediment and playa[6] in the North, where the decrease in groundwater is much more because of there is more water use. This has a crucial role in accelerating desertification. The average decline in the groundwater table in the southern area reaches 20 cm per year, and in north 45 cm (Sadeghi Ravesh 2008; Kazemi Nejad 1996).

Decline in groundwater table—in other words, overdraft of groundwater resources—is caused by human mismanagement in the Khezr Abad region. Among these, improper human activities affecting desertification are included:

- Territorial irrigation methods (including basin and flooding irrigation) with low efficiency and much more waste water consumption; 73.8 % of farmers apply traditional irrigation systems in the study area;
- Increase in cultivation leads to drilling of deep wells;
- Existing outdoor ponds and streams have high pores and low efficiency; 77 % of irrigation networks outdoors have efficiency of <40 %;
- Small area of farming lands, on average <10 acres to each farmer;
- Increase in industries with high water consumption such as sand-washing, dyeing and textile industries;
- Increase in water harvesting as a result of motorized wells;
- Unsuitable dimension of agriculture lands;

[5] The study area is a part of this basin.

[6] Also known as an 'alkali flat' or 'sabkha', a desert basin with no outlet which periodically fills with water to form a temporary lake.

Table 9 Fuzzy decision-making matrix of optimal combating-desertification alternatives from group viewpoint

Alternatives priority (A)	Criteria importance (C)					$\overline{P}_i$
	C_2 0.326	C_5 −0.00296	C_6 0.686	C_7 −0.0048	C_{16} −0.00296	
A_{18}	0.115	−0.035	−0.299	−0.11	0.186	0.018
A_{20}	0.0098	0.768	0.075	−0.172	0.177	0.052
A_{23}	−0.027	−0.035	−0.0299	0.051	0.186	0.030
A_{31}	0.813	0.279	0.972	0.209	0.076	0.93
A_{33}	0.108	0.023	0.0125	0.102	0.373	0.038

- Increase in water harvesting to irrigate the cultivated areas of *Haloxylon* species developed recently to control wind erosion in clay area and sandy dunes of Ashkezar erg.

The results of the fuzzy AHP model application in Khezr Abad show that among 16 effective criteria of the present alternatives and 40 proposed alternatives to control and decrease desertification phenomena, only modification of groundwater harvesting (A_{31}) with a preference degree of 0.93 can combat desertification based on the criteria set, and other alternatives have only an insignificant role in controlling and decreasing this phenomenon in the study area. So, a change of irrigation patterns from traditional systems such as flood, basin and furrow irrigation to pressurized systems such as drip irrigation (Schneier-Madanes and Marie-Françoise 2010b, pp. 75–87) and Qanat dredging (Schneier-Madanes and Marie-Françoise 2010a, pp. 125–139) are suggested in the study area.

4 Conclusion

The results of this research indicate that the fuzzy AHP model is really efficient to present optimal alternatives in controlling and decreasing desertification and also in reclaiming degraded lands. By applying the results of the present study, desert area managers are able to save in facilities and funds allocated to controlling desertification. To sum up, national capital loss can be prevented by achieving better results.

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