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Application of AHP and ELECTRE models for assessment of de-desertification alternatives

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Abstract

The assessment of de-desertification alternatives can be effective in controlling the reclamation of disturbed land and avoiding destruction of areas at risk. Until now, there has been no method to consider different criteria and alternatives, or to present the optimum alternatives based on systematic structures and experts' perspectives. Desertification is a complex process resulting from various factors, including anthropogenic activities; the selection of optimum alternatives is a very difficult task. This paper attempts to represent the optimum alternatives based on the Multiple Attribute Decision-Making Model (MADM). For this purpose, the initial priorities for alternatives were determined by Expert Choice (EC) software via Elimination and Choice Translating Reality (known as ELECTRE). Then, the final priorities for alternatives were assessed using the Analytical Hierarchy Process (AHP). This model was tested in the Khezr Abad region, Yazd Province, to evaluate the determination of optimum alternatives. The results indicated that prevention of unsuitable land use changes, vegetation cover development and reclamation, and changes in groundwater harvesting, with weight averages of 22.9, 21.8 and 19.1 %, respectively, are the most important desertification alternatives in the study area.

Keywords: De-desertification; AHP; MADM; ELECTRE Model; Pairwise comparison; Khezr Abad region

1. Introduction

Arid and semi-arid environments cover more than 40 % of the global land surface (Deichmann and Eklundh, 1991) and provide habitat to more than a billion people (UNSCO Office to Combat Desertification and Drought, 1997; Reynolds and Stafford Smith, 2002). According to the United Nations Conference on Desertification (UNCOD, 1977), the desertification process threatens more than 785 million people in arid regions. Of this number, 60 to 100 million people are affected directly due to the loss of land fertility and other desertification processes (Meshkat, 1998). In Iran, 100 million hectares are affected by desertification processes, especially wind erosion, water erosion and physicochemical factors (Research Institute of Forest, Rangeland and Watershed, 2005).

The term "de-desertification" includes activities which are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development which are aimed at: (i) prevention/reduction of land degradation; (ii) rehabilitation of partly degraded land; and (iii) reclamation of desertified land (Law Office of Environment and Parliamentary Affairs, 2004). Based on this framework, this study tries to represent a systematic approach to provide effective solutions among the several solutions based on different desertification criteria. Therefore, in order to achieve this goal in the context of decision-making models, Analytical Hierarchy Process (AHP) and ELECTRE, a kind of compensatory multiple criterion decision-making model, were applied to rank alternatives for combating desertification.

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Multiple Criteria Decision-Making (MCDM) is one of the most common decision-making models used in fields such as sciences, business, engineering, etc. Moreover, the MCDM method can help to improve the quality of decision-making by explicit, clear, logical and efficient decision processes (Wang and Triantaphyllou, 2008). This method is known to be an analytical method for qualitative and quantitative criteria with high performance. Thus, important advantages of this approach are its ability to focus on the decision-maker's needs and propose a suitable approach to assessment (Huang and Chen, 2005).

The AHP method is widely used in decision-making processes. In this method, any decision problem is formed in terms of hierarchy, with different levels of criteria and alternatives. Elements of different levels are then compared through pairwise comparison. Finally, valuation is made based on two criteria of priority (Shaw and Wheeler, 1985; Chen, 2001).

Recent studies that offered alternatives to solve desertification problems have been non-comprehensive. There is no record of the use of any systematic models. The only work involving systematic techniques and the presentation of optimal alternatives for combating desertification is to be found in Grau *et al*. (2010) and Sadeghi Ravesh *et al*. (2011). Grau *et al*. (2010) used the three models of ELECTRE, AHP and PROMETHEE to find the optimal alternatives in order to provide an integrated plan to control erosion and desertification. The obtained results indicate the high performance of these models for presenting optimal de-desertification alternatives. In addition, Sadeghi Ravesh *et al*. (2011) used the AHP model to prioritize alternatives to combat desertification based on EC software.

Recently, different theoretical and practical researches have been carried out on the application of AHP and ELECTRE models, including approaches such as selecting personnel (Afshari *et al*., 2010), rating alternative plans (Dodangeh *et al*., 2010), selecting design alternatives for high-speed railroads (Antón *et al*., 2004), selecting the most suitable system for solid waste disposal (Anton *et al*., 2006), water resource management (Grau *et al*., 2009), safety evaluation (Schinas, 2007), prioritizing factory products (Rezvani and Mehdipoor Hosseinabad, 2009) and equity selection (Ahmadpoor *et al*., 2009). In all the abovementioned studies, at first, a hierarchical structure was designed, and criteria were then weighted using the ELECTRE method, and finally the choices offered were ranked using AHP technique.

In summary, the advantages of these methods are: (1) involvement of quantitative and qualitative criteria in the decision-making process; (2) simplicity of application; (3) consideration of many criteria in the decision-making process, (4) ability to change entered information and to evaluate system responsibility based on this change; (5) if some criteria are negative, such as "cost per alternative" and others are positive, such as "access to a relevant expert for each alternative", the ELECTRE method offers an ideal alternative that is a combination of the best accessible values of all criteria; (6) this method has the ability to graphically display alternatives' priority (Azar and Rajabzadeh, 2002).

In order to carefully select appropriate alternatives and prevent human error, a computer program has been used in this study. This program has been written by the Expert Choice Company. The first version of this software appeared in 1984 and the last one was revised in 2002 (Ghodsi Pour, 2002).

2. Material and methods

2.1. Study area

The Khezr Abad region of 78,180 ha area is located in the western part of Yazd Province, central Iran, within the 31º 45´ to 32º 15´ northern latitudes and the 53º 55´ to 54º 20´ eastern longitudes. The climate of this region is cold and arid based on the Amberje climate classification. About 12,930 ha (16 %) of the region consists of the hills and sandy area which are part of the Ashkezar great erg, located in the northern part of the study area. About 9,022 ha (12 %) of the area consists of bare lands and infrastructures such as clay plain and rocky masses. In addition, about 1995 ha (26.5 %) of all the agriculture lands of the region consist of destroyed lands resulting from human activities and natural processes, which shows an absolutely typical condition of desertification in the study area and presents the necessity to pursue effective and optimum de-desertification solutions and alternatives. For this aim, the ELECTRE[1] and AHP[2] (one of the most important and comprehensive multiple attribute decision models) methods were utilized to select the optimal de-desertification alternatives.

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[1] Elimination et (and) Choice Translating Reality

[2] Analytical Hierarchy Process

2.2. Methodology

2.2.1. Establishment of decision-making matrix

2.2.1.1. Selection of effective criteria and alternatives

Selecting criteria and alternatives can be done individually, according to expert experience, resources and field studies, or using the Delphi method, distributing a structured questionnaire among experts familiar with the study area. The Delphi method was used to identify important and preferred criteria and alternatives regarding the group, and to establish a hierarchical structure. Therefore, records of expert interviews are accumulated to draw up a basic criterion through a question and answer approach. The experts were asked to rate effective criteria and alternatives between 0 and 9. Finally, mean values were calculated. In this case, if the mean value was less than 7 ($\overline{X} < 7$), the related criterion and alternative were removed, and if the mean value was greater than or equal to 7 ($\overline{X} \geq 7$), the related criterion and alternative were used to design a hierarchical decision structure in three levels: purpose, criteria and alternatives, (Azar and Rajabzadeh, 2002).

2.2.1.2. Establishment of group pairwise comparison matrix

The structured questionnaire was designed based on the literature, and the nine-point Saaty scale, from 1(least important) to 9 (most important), was used to measure the relative importance of criteria and the priority of de-desertification alternatives (Table 1).

Table 1. Importance and priority based on nine-point Satty scale (Satty, 1980)

Score	Importance Degree	Priority Degree in Pairwise Comparison
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
	1/2, 1/3,1/4, …., 1/9	Mutual Values

The questionnaire was distributed among 25 experts familiar with the study area. Then, using geometric mean and an assumption of the uniformity of an expert's opinion, pairwise comparisons of each expert (Table 2) were composed according to Eq. 1, and pairwise comparisons were made relating to each group.

$$\bar{a}_{ij} = \left(\pi_{K=1}^{N} a_{ij}^{k}\right)^{1/N} \quad (1)$$

In this equation, aijk = component of k expert to comparison i and j. So, āij (geometric mean) for all corresponding components is obtained by Eq. 1 (Azar and Rajabzadeh, 2002; Ghodsi Pour, 1998).

Table 2. Pairwise comparisons matrix

$$A = \begin{matrix} a_{11} & a_{12} & \ldots\ldots\ldots\ldots & a_{1n} \\ a_{21} & a_{22} & \ldots\ldots\ldots\ldots & a_{2n} \\ : & : & : & : \\ a_{n1} & a_{n2} & \ldots\ldots\ldots\ldots & a_{nn} \end{matrix} \qquad A=[a_{ij}] \quad i,j=1,2,\ldots,n$$

$a_{ij=}$ preference of i criteria to j criteria

2.2.1.3. Compute the priorities based on group pairwise comparisons of tables

At this stage, the numbers of the group pairwise comparison matrix (values of criteria's importance and alternatives' priority for each criterion) were imported in EC software (Ghodsi Pour, 2002). After normalization using Eq. 2, the importance and percentages of priorities were presented as bar graphs using harmonic mean method, or the average of each level of normalized matrix (Fig. 2 and 3).

$$\overline{rij} = \frac{\overline{aij}}{\sum_{i=1}\overline{aij}} \quad (2)$$

In this equation:

$\bar{r}_{ij}$ = normal component

ij ā = group pairwise comparison component of i to j

Σāij = total column of group pairwise comparisons

2.2.1.4. *Formation of Normalized Decision Matrix (NDM)*

At this stage, the weight values of criteria importance (Wj) and alternatives' priority (Pij) are considered in the form of a decision matrix based on any criteria.

Table 3. Normalized Decision Matrix

Alt	Criterion				
	C_1	C_2	C_3	-----------	C_n
	W_1	W_2	W_3	-----------	W_n
A_1	P_{11}	P_{12}	P_{13}	--------	P_{1n}
A_2	P_{21}	P_{22}	P_{23}	-----------	P_{2n}
:	:	:	:	:	:
A_m	P_{m1}	P_{m2}	P_{m3}	-----------	P_{mn}

In this matrix: m= the number of choices or alternatives, n= number of criteria, C= title of criteria, W= weight value of related criteria, a_{ij}= weight value each alternative gains in relation to related criteria.

2.2.2. *Ranking alternatives using ELECTRE*[1]

The ELECTRE method is one of the most important compensation techniques, and was presented by Roy (1991) in response to the lack of existing decision-making models. Application of this model is based on outranking relationships. Results obtained from this method are based on a set of rankings. All steps in this method are designed according to a concordance and discordance set. This method has developed in recent years and different versions have been presented for decision-making in various fields. For example, ELECTRE I and IS are used to select the issues, ELECTRE TRI to arrange issues and problems, and II and IV ELECTRE III to classify the problems (Roy, 1991; Kangas *et al.*, 2001; Figueira and Roy, 2005; Wang and Triantaphyllou, 2008). All these versions are based on the fundamental concept that Roy offered but with somewhat different methods (Huang and Chen, 2005). Today, this model is widely used in Multiple Attribute Decision-Making (MADM) in the fields of civil and environmental engineering including: for assessment of civil engineering projects, selecting a location for nuclear waste, construction of new nuclear reactors, etc. (Hobbs and Meier, 2000). Since the ELECTRE III version has been used in several projects in order to solve natural resource problems (Kangas *et al.*, 2001), in this study, therefore, ELECTRE III was used to rank desertification alternatives. The steps in this method can be expressed as follows:

2.2.2.1. *Formation of weighted decision matrix (HDM)*

In order to establish the weighted decision matrix (HDM), the following equation was used:

$$HDM= DM \times W_{n\times n} \quad (3)$$

where:

DM= Decision matrix

$W_{n\times n}$= Diagonal matrix of criteria weight. In this matrix, the main diagonal value is equal to the criteria weight and the other components' values are zero (Table 3).

The weight value of each criterion is determined by determiner or scientific methods such as Shannon Entropy, eigenvector, least squares weighted, and linear programming for multidimensional analysis of preference.

2.2.2.2. *Determination of concordance and discordance set for each pair of alternatives*

At this stage, all alternatives are evaluated relative to all criteria based on pair and concordance, and discordance sets are formed. The concordance set (S_{kl}) from the k and l alternatives includes all criteria that determine that A_k alternative is more desirable than A_l alternative. On the other hand:

If P_{ij} is increasing desirable

$$S_{kl} = \{j | P_{kj} \geq P_{lj}\} \quad j = 1,...,m \quad (4)$$

If P_{ij} is decreasing desirable

$$S_{kl} = \{j | P_{kj} \leq P_{lj}\} \quad j = 1,...,m \quad (5)$$

The discordance set (D_{kl}) that determines that A_k alternative is less desirable than A_l alternative, on the other hand:

If P_{ij} is increasing desirable

$$D_{kl} = \{j | P_{kj} < P_{lj}\} \quad j = 1,...,m \quad (6)$$

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[1] Elimination et (and) Choice Translating Reality

If P_{ij} is decreasing desirable

$$D_{kl} = \{j | P_{kj} > P_{lj}\} \quad j = 1,\dots,m \tag{7}$$

2.2.2.3. Calculation of concordance matrix

This matrix is a square matrix of m×m in which its diameter has no element. Other elements of the matrix are obtained by total weights of criteria belonging to the concordance set according to Eq. 8.

$$I_{kl} = \sum_{j \in S_{kl}} W_j; \quad \sum_{j=1}^{n} W_j = 1 \quad k,l = 1,2,...m, k \neq 1 \tag{8}$$

Criteria concordance indicates the relative importance of A_k to A_l alternative. Thus, each component of the concordance matrix is between 0 and 1 $(0 \leq I_k \leq 1)$.

Table 4. Diagonal matrix of the criteria weight to presentde-desertification alternatives

$$W_{n \times n} = \begin{vmatrix} W_1 & 0 & 0 & 0 & 0 \\ 0 & W_2 & 0 & 0 & 0 \\ 0 & 0 & W_3 & 0 & 0 \\ . & . & . & .... & . \\ 0 & 0 & 0 & 0 & W_n \end{vmatrix}$$

2.2.2.4. Calculation of discordance matrix

This matrix is defined with NI and, like the concordance matrix, is an m×m matrix. The main matrix diameter has no element; other components are calculated by a no-scale harmonic matrix according to Eq. 9.

$$NI_{kl} = \frac{\underset{j \in D_{kl}}{MAX} \left| WNDM_{kj} - WNDM_{lj} \right|}{\underset{j \in J}{MAX} \left| WNDM_{kj} - WNDM_{lj} \right|} \tag{9}$$

The NI matrix expresses the non-desirable ratio of the k and l discordance matrix to the total discordance in the indices.

2.2.2.5. Determination of Concordance Dominance Matrix (CDM)

I_{kl} values from the concordance matrix must be measured to a threshold value until chance for alternative priority A_k to be judged better than A_l. To determine threshold value ($\bar{I}$), past information and decision-making opinion can be used. A general criterion for determining this threshold is calculated by the value matrix mean based on Eq. 10:

$$\bar{I} = \sum_{L=1}^{m} \sum_{K=1}^{m} \frac{I_{K,L}}{m(m-1)} \tag{10}$$

In this matrix m is matrix dimensions.

Based on threshold ($\bar{I}$), F Boolean matrix is formed (0 and 1) based on Eq. 11 and 12:

$$f_{K,L} = 1 \quad \text{if} \quad I_{K,L} \geq \bar{I} \tag{11}$$

$$f_{K,L} = 0 \quad \text{if} \quad I_{K,L} \leq \bar{I} \tag{12}$$

2.2.2.6. Determination of Discordance Dominance Matrix (DDM)

$NI_{K,L}$ ingredients of the discordance matrix must be measured based on a threshold value. The threshold is calculated based on Eq. 13:

$$\overline{NI} = \sum_{L=1}^{m} \sum_{K=1}^{m} \frac{NI_{K,L}}{m(m-1)} \tag{13}$$

Then G Boolean matrix entitled “effective discordance matrix” is formed according to Eq. 14 and 15:

$$g_{K,L} = 1 \quad \text{if} \quad NI_{K,L} \leq \bar{I} \tag{14}$$

$$g_{K,L} = 0 \quad \text{if} \quad NI_{K,L} \geq \bar{I} \tag{15}$$

2.2.2.7. Determination of Aggregate Dominance Matrix (ADM)

This matrix is calculated by a combination of concordance dominance matrix and discordance dominance matrix based on Eq. 16. This matrix shows the relative priority of alternatives.

$$h_{K,L} = f_{K,L} \times g_{K,L} \tag{16}$$

2.2.2.8. Removing ineffective alternatives and classifying them

The general matrix of H represents the priority of different alternatives relative to each other. In this matrix, the columns of alternatives that are formed with a number of less than one have higher priority than other alternatives. So, priority alternatives are selected, and other alternatives are removed. Based on this method, sometimes the priority of several alternatives is estimated to be equal; in this case, for evaluation of the alternatives’ priority, the Analytical Hierarchy Process is used.

2.2.3. Ranking alternatives using the Analytical Hierarchy Process

The AHP model was introduced by Thomas L. Saaty in 1980; it is one of the most comprehensive multiple attribute decision models. This method formulates the issues in a framework of hierarchical structure, as well as considering different quantitative and qualitative criteria in the issue. AHP method infers different choices in a decision and is able to perform sensitive analysis of criteria and sub-criteria. Furthermore, it is flexible in relation to changes in effective desertification factors in the future. Moreover, it is established according to pairwise comparison that facilitates judgements and calculations, and uses systematic group participation to select alternatives. In addition, it shows the level of decision compatibility and incompatibility, and has a strong theoretical basis that was established based on certainly principles (Asgharpour, 1992; Ghodsi Pour, 2002; Sadegh Ravesh, 2011). The structure of the model is formed by three levels including: objectives, criteria and alternatives. Criteria and alternatives are important to achieving the goal. After selecting priorities based on group pairwise comparisons (part 2.2.1.3), and formation of a Normalized Decision Matrix (2.2.1.4), to achieve the goal of “optimum de-desertification alternatives” incompatible pairwise comparisons are evaluated using AHP. Then, the final weight and alternatives’ ranking is determined. The specific steps involved in the development and analysis of this model are as follows:

2.2.3.1. Study of the incompatible pairwise comparisons

In the Analytical Hierarchy Process (AHP), when the criteria’s importance (W_j) and alternatives’ priority (P_{ij}) are calculated based on any criterion’s relation to others, there is the possibility of inconsistency in judgements. So, the level of inconsistency of judgements must be determined. A model mechanism for considering judgements’ inconsistency is to calculate one coefficient entitled “inconsistency rate” that is obtained by division of the “inconsistency index” from the “randomness index”. If this ratio is less than 0.1, consistency in judgements is acceptable. Otherwise, judgements must be revised. On the other hand, the pairwise matrix of indices must be formed again. The inconsistency index (II) of the group comparisons is calculated by Eq. 17.

$$\text{I.I} = \frac{\lambda\text{max} - \text{n}}{\text{n}} \qquad (17)$$

Inconsistency index for random (IIR is extracted from Table 5) according to the number of indices.

Table 5. Randomness inconsistency index (Saaty and Hager, 1995)

n	1	2	3	4	5	6	7	8
IIR	0	0	0.58	0.90	1.12	1.34	1.32	1.41
n	9	10	11	12	13	14	15	-
IIR	1.45	1.49	1.51	1.48	1.56	1.57	1.59	-

In a particular vector method, Eq. 18 is used to calculate maximum special value (${}^{a}\text{max}$).

$${}^{a}\text{max} = \frac{1}{n}\left[\sum_{i=1}^{n}\left(AW_i / W_i\right)\right] \qquad (18)$$

AW_i is a vector that is calculated by multiplication of the alternatives’ group pairwise matrix (P_{ij}) in the weight vector, or the importance coefficient of criteria (W_j) and the sum of each row, entitled weight sum vector (WSV). Then the consistency vector (CV) is calculated by division of each component of the weight sum vector, and finally the inconsistency ratio (IR) is calculated by Eq. 19 (Saaty, 1995; Ghodsi Pour, 1998).

$$\text{IR} = \frac{\text{II}}{\text{IIR}} \qquad (19)$$

2.2.3.2. Selection of the best alternative or determining the final weight of alternatives

In order to determine the important alternatives and rank priorities, a synthesis process was applied on the results obtained by the previous steps using the weighted average method based on AHP (Table 3). The final weight of each alternative ($\overline{\text{P}}\text{i}$) is calculated by the total multiplication weight of each criterion (W_j) in the alternative weight related to that criterion (P_{ij}) (Eq. 20), and the diagram of alternatives’ priority is formed based on the criteria set (Ghodsi Pour, 1998).

$$\overline{\text{P}}\text{i} = \sum_{i=1}^{M}{}_{j=1}^{N} \text{Wj} * \text{Pij} \qquad (20)$$

Table 6. Decision matrix in Analytical Hierarchy Process

Alt	Criterion					$\bar{P}_i$
	C_1	C_2	C_3	-----------	C_n	
	W_1	W_2	W_3	-----------	W_n	
A_1	P_{11}	P_{12}	P_{13}	--------	P_{1n}	$\bar{P}_1$
A_2	P_{21}	P_{22}	P_{23}	-----------	P_{2n}	$\bar{P}_2$
:	:	:	:	:	:	:
A_m	P_{m1}	P_{m2}	P_{m3}	-----------	P_{mn}	$\bar{P}_m$

In this matrix m= the number of alternatives, n= number of criteria, C= title of criteria,
W= weight value of related criteria, Pij= weight value each alternative gains in relation to related criteria,
$\bar{P}_i$ = preference degree for each alternative

3. Results

3.1. Selection of criteria and alternatives in relation to group and establishment of a hierarchical structure of decisions

Thus, the Delphi method was used to identify important and preferred criteria and alternatives, and to establish a hierarchical structure (Saaty, 1995). For this purpose, a structured questionnaire in two parts, including criteria and alternatives (Table 7), was distributed among experts familiar with the study area. Then, the arithmetical mean was used to calculate the mean of the obtained results. Finally, mean values were calculated. In this case, if the mean value was less than 7 ($\bar{x}<7$), the related criterion and alternative were removed, and if the mean value was more than or equal to 7 ($\bar{x}\geq 7$), the related criterion and alternative were used to design a hierarchical decision structure (Fig. 1).

Table 7. The offered alternatives for de-desertification

– Modification, creation and development of socioeconomic 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 of punishments for crime
A_9– Providing for 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 de-desertification
A_{12}– Organization of urban areas and prevention of 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 of desert instead of mono-utilization
A_{17}– Allocation of 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 of heavy agricultural and industrial machinery traffic
A_{27}– Create living and non-living wind breaks 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 and spraying methods

– Development and sustainable management of water resources
A_{31}– Modification of groundwater harvesting
A_{32}– Reduction of 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
A_{35}– Optimal collecting and harvesting of water resources (including: river isolation, repair and dredging of *qanat*, utilization of canals and streams, desalination of salty waters, etc.)
A_{36}– Groundwater fed
A_{37}– Construction of flood broadcast networks and the use of 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

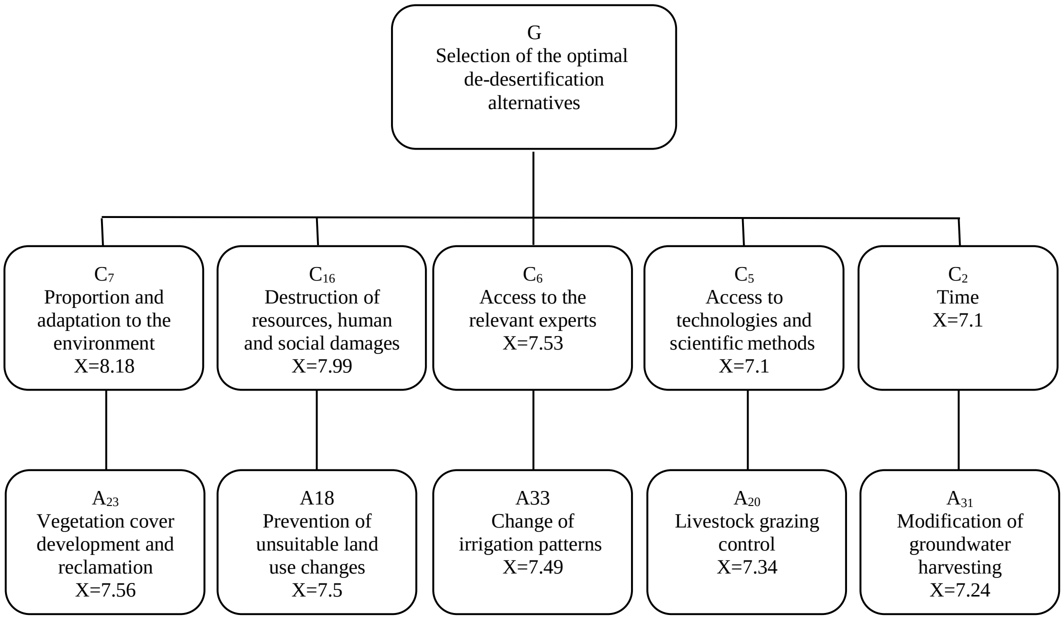


Fig. 1. Hierarchical decision structure to select optimal de-desertification alternatives in study area

3.2. Calculation of relative weight of criteria and alternatives, and formatting of group decision matrix (DM)

After selecting important and preferred criteria and alternatives according to the group, the Delphi method of group pairwise comparison matrices was used to determine the relative weight of criteria and alternatives to achieve the goal of “offering optimal de-desertification alternatives” (Table 8). A second questionnaire entitled “pairwise comparisons questionnaire” was designed based on selected criteria and alternatives: the results of the first questionnaire. Then, the group pairwise comparisons matrix of the criteria’s importance to the goal and the priority of alternatives in relation to each criterion was formed by obtaining expert opinions and combining their ideas with those of the experts from the geometric mean (Eq. 1). In this paper, only the alternatives’ priority matrix to the criterion of “proportion and adaptation to the environment” is expressed (Table 9). The matrices of the alternatives’ priority to other criteria are calculated in this way.

Table 8. Pairwise comparison matrix of the criteria’s importance to the goal of “offering optimal de-desertification alternatives”

Criterion	C_{16}	C_6	C_5	C_2
C_7	1.2	2.5	2.5	3.4
C_{16}		2.3	3.1	3.1
C_6			1.7	2
C_5				1.3

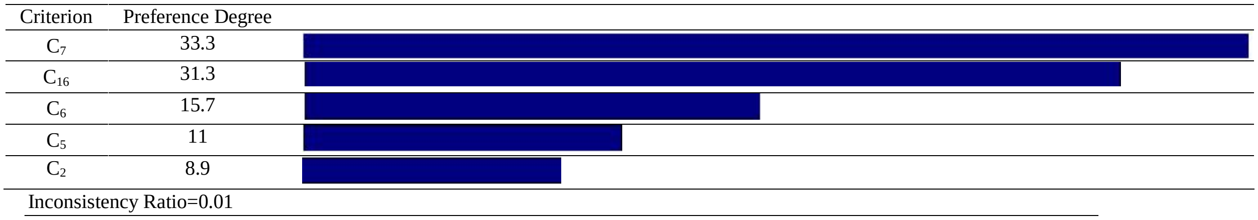
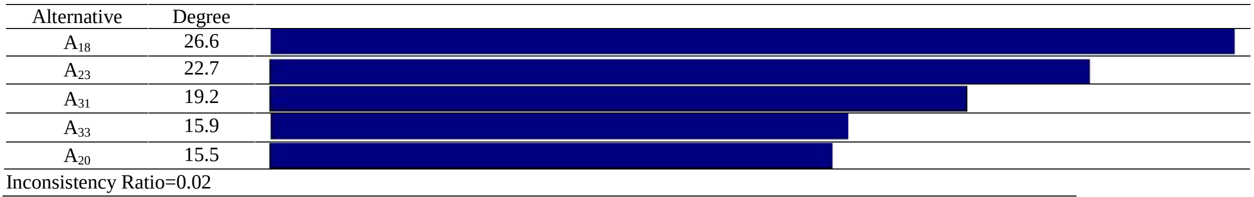


Fig. 2. Comparison of proposed criteria’s importance to achieving the goal

Table 9. Group pairwise comparison matrix of alternatives' priority according to the criteria of "proportion and adaptation to the environment"

Alternative	A_{23}	A_{31}	A_{33}	A_{20}
A_{18}	(1.1)	1.3	2.4	1.6
A_{23}		(1.1)	1.6	1.3
A_{31}			(1.1)	1.2
A_{33}				1.2



Alternative	Degree
A_{18}	26.6
A_{23}	22.7
A_{31}	19.2
A_{33}	15.9
A_{20}	15.5

Inconsistency Ratio=0.02

Fig. 3. Comparison of alternatives' rate of preference according to the criteria of "proportion and adaptation to the environment"

Then, matrix values of the criteria's importance and the priorities of alternatives (Table 8, 9) were entered into EC software based on each criterion, and the importance and priority of de-desertification criteria and alternatives were obtained according to the group in the study area as bar graphs based on percentages using normalization and harmonic mean (Fig. 2, 3).

Considering these graphs, it is observed that the alternatives are different based on each criterion. Therefore, a decision-making matrix of optimal de-desertification alternatives according to group (Table 3) was formed to select the final alternatives and classification of their priorities, in a general framework of decision-matrix in AHP (Table 8). Finally, based on the ELECTRE model, optimal alternatives were determined in the following stages.

3.3. Design of harmonic decision matrix of optimal alternatives for combating desertification

After formation of the desertification decision matrix (Table 10), each component of the above matrix was harmonized by means of Eq. 3 and the harmonic decision matrix was formed (Table 11). Here, to calculate the diagonal matrix, the criteria weight (W_j) was determined using EC software based on normalization method and calculated harmonic average.

Table 10. Decision matrix of optimal de-desertification alternatives according to group

Criteria importance (C) ►	C_2	C_5	C_6	C_{16}	C_7
Alternatives priority (A) ▼	0.0892	0.1095	0.1576	0.3074	0.3365
A_{23}	0.2509	0.2387	0.2488	0.1805	0.2257
A_{18}	0.1960	0.1635	0.1983	0.2383	0.2643
A_{33}	0.1620	0.2565	0.2093	0.1510	0.1599
A_{20}	0.2229	0.1762	0.1608	0.2209	0.1582
A_{31}	0.1682	0.1633	0.1826	0.2092	0.1918

3.4. Design of the consistency and inconsistency matrix of de-desertification alternatives

After designing the harmonic decision matrix of optimal de-desertification alternatives (Table 11), to calculate the consistency and inconsistency matrix, a consistency and inconsistency set must be presented. The harmonic decision matrix shows increasing desirability; on the other hand, if the number allocated to each alternative related to each criterion is more, the priority of that alternative as a goal is greater. To present the consistency and inconsistency set (Table 12), Eq. 4 and 4 are used.

Then, consistency (Table 13) and inconsistency sets (Table 14) of de-desertification alternatives are obtained using Eq. 8 and 9.

3.5. Determination of the threshold and design of effective consistency and inconsistency matrix of de-desertification alternatives

In this phase, using Eq. 10 and 13, the consistency and inconsistency thresholds of de-desertification alternatives were estimated to be 0.49 and 0.71, respectively; effective consistency and inconsistency matrices were formed based on Eq. 11 and 14.

Table 11. Harmonic decision matrix of optimal de-desertification alternatives according to group

Criteria importance (C) ► Alternatives priority (A) ▼	C2	C5	C6	C16	C7
A23	0.0223	0.0261	0.0392	0.0554	0.0759
A18	0.0174	0.0179	0.0312	0.0732	0.0889
A33	0.0145	0.0280	0.0329	0.0464	0.0538
A20	0.0198	0.0192	0.0253	0.0679	0.0532
A31	0.0150	0.0178	0.0287	0.0643	0.0645

Table 12. Consistency and inconsistency sets of de-desertification alternatives

$D_{K,L}$		C_2	C_5	C_6	C_{16}	C_7	$S_{K,L}$
C_7, C_{16}	$D_{A23, A18}$	1	1	1	0	0	$S_{A23, A18}$
C_{16}, C_5	$D_{A23, A33}$	1	0	1	0	1	$S_{A23, A33}$
C_{16}	$D_{A23, A20}$	1	1	1	0	1	$S_{A23, A20}$
C_{16}	$D_{A23, A31}$	1	1	1	0	1	$S_{A23, A31}$
C_6, C_5, C_2	$D_{A18, A23}$	0	0	0	1	1	$S_{A18, A23}$
C_6, C_5	$D_{A18, A33}$	1	0	0	1	1	$S_{A18, A33}$
C_5, C_2	$D_{A18, A20}$	0	0	1	1	1	$S_{A18, A20}$
0	$D_{A18, A31}$	1	1	1	1	1	$S_{A18, A31}$
C_7, C_6, C_2	$D_{A33, A23}$	0	1	0	1	0	$S_{A33, A23}$
C_7, C_{16}, C_2	$D_{A33, A18}$	0	1	1	0	0	$S_{A33, A18}$
C_{16}, C_6, C_2	$D_{A33, A20}$	0	1	0	0	1	$S_{A33, A20}$
C_7, C_2	$D_{A33, A31}$	0	1	1	1	0	$S_{A33, A31}$
C_7, C_6, C_5,C_2	$D_{A20, A23}$	0	0	0	1	0	$S_{A20, A23}$
C_7, C_{16}, C_6	$D_{A20, A18}$	1	1	0	0	0	$S_{A20, A18}$
C_7, C_6, C_5	$D_{A20, A33}$	1	0	0	1	0	$S_{A20, A33}$
C_7, C_6	$D_{A20, A31}$	1	1	0	1	0	$S_{A20, A31}$
C_7, C_6, C_5,C_2	$D_{A31, A23}$	0	0	0	1	0	$S_{A31, A23}$
C_7, C_{16}, C_6,	$D_{A31, A18}$	0	0	0	0	0	$S_{A31, A18}$
C_{16}, C_6, C_5	$D_{A31, A33}$	1	0	0	0	1	$S_{A31, A33}$
C_7, C_5, C_2	$D_{A31, A20}$	0	0	1	0	1	$S_{A31, A20}$

Table 13. Consistency matrix of de-desertification alternatives

$$I_{K,L} = \begin{vmatrix} - & 0.356 & 0.583 & 0.692 & 0.692 \\ 0.644 & - & 0.733 & 0.801 & 1 \\ 0.417 & 0.267 & - & 0.446 & 0.574 \\ 0.307 & 0.198 & 0.396 & - & 0.506 \\ 0.307 & 0 & 0.426 & 0.494 & - \end{vmatrix}$$

Table 14. Inconsistency matrix of de-desertification alternatives

$$NI_{K,L} = \begin{vmatrix} - & 1 & 0.416 & 0.55 & 0.78 \\ 0.46 & - & 0.287 & 0.067 & 0 \\ 1 & 1 & - & 0.404 & 1 \\ 1 & 1 & 1 & - & 1 \\ 0.92 & 1 & 0.95 & 0.424 & - \end{vmatrix}$$

3.6. Computation of the priority matrix of alternatives for combating desertification

In order to determine the priority of de-desertification alternatives, effective consistency and inconsistency matrices (Table 15, 16) were combined and a priority matrix of alternatives to combat desertification was designed (Table 16).

Table 15. Effective consistency matrix of de-desertification alternatives

$$F_{K,L} = \begin{vmatrix} - & 0 & 1 & 1 & 1 \\ 1 & - & 1 & 1 & 1 \\ 0 & 0 & - & 0 & 1 \\ 0 & 0 & 0 & - & 1 \\ 0 & 0 & 0 & 1 & - \end{vmatrix}$$

Table 16. Effective inconsistency matrix of de-desertification alternatives

$$G_{K,L} = \begin{vmatrix} - & 0 & 1 & 1 & 0 \\ 1 & - & 1 & 1 & 1 \\ 0 & 0 & - & 1 & 0 \\ 0 & 0 & 0 & - & 0 \\ 0 & 0 & 0 & 1 & 1 \end{vmatrix}$$

Based on Table 18, it is implied that the prevention of unsuitable land use changes (A_{18}), vegetation cover development and reclamation (A_{23}) and modification of groundwater harvesting (A31) are the most important alternatives in desertification. Among alternatives, changes of irrigation patterns (A_{33}) and livestock grazing control (A_{20}) have no priority over each other. So the AHP model is used to determine the final priority of alternatives that have the same priority using the ELECTRE model. The results of this model are as follows:

Table 17. Priority matrix of de-desertification alternatives based on ELECTRE method

$$H_{K,L} = \begin{vmatrix} - & 0 & 1 & 1 & 0 \\ 1 & - & 1 & 1 & 1 \\ 0 & 0 & - & 0 & 0 \\ 0 & 0 & 0 & - & 0 \\ 0 & 0 & 0 & 1 & - \end{vmatrix}$$

3.7. Study of consistent comparisons and determination of final priority of alternatives using AHP

Because of its ease, speed and accuracy in achieving results, the EC model was used to compute "incompatibly rate". The results showed that the incompatibility rate of all matrices was calculated as 0.01, which is lower than Saaty's acceptable value (0.1>). Finally, after determining the compatibility between judgements, the Normalized Decision Matrix components of de-desertification alternatives were combined by Eq. 20, and alternatives' priority was computed based on the criteria.

Table 18. Decision matrix of optimal de-desertification alternatives according to group

Criteria importance(C) ► Alternatives priority(A)▼	C_2	C_5	C_6	C_{16}	C_7	$\overline{P}_i$
	0.0892	0.1095	0.1576	0.3074	0.3365	
A_{23}	0.2509	0.2387	0.2488	0.1805	0.2257	0.2192
A_{18}	0.1960	0.1635	0.1983	0.2383	0.2643	0.2288
A_{33}	0.1620	0.2565	0.2093	0.1510	0.1599	0.1758
A_{20}	0.2229	0.1762	0.1608	0.2209	0.1582	0.1875
A_{31}	0.1682	0.1633	0.1826	0.2092	0.1918	0.1905

The obtained results of the final priority alternatives by AHP confirm the obtained results of the ELECTRE method. The alternatives of prevention of unsuitable land use changes (A_{18}), vegetation cover development and reclamation (A_{23}) and modification of groundwater harvesting, with 22.9, 21.9 and 19.05 %, respectively, were placed in first to third order. By contrast, the two alternatives of change of irrigation patterns (A_{33}) and livestock grazing control (A_{20}), which using the previous method had the same priority; were here identified clearly in terms of their priority. Thus, livestock grazing control alternative (A_{20}) with 18.6 % was ranked a higher priority than the change of irrigation patterns alternative (A_{33}) with 17.6 %.

4. Conclusion and Discussion

In this study, a novel technique was presented to rank the priority of alternatives for combating desertification. This model was employed in the Khezr Abad region to determine optimal de-desertification alternatives. High performance, easy application of the described model using software such as MS, EXCEL and EC, and the assessment of alternatives based on a set of criteria are features of this model. But ignoring decision-makers' fuzzy judgement is a limitation of the model. Furthermore, some criteria have a qualitative or unknown structure that cannot be accurately measured. In such a case, fuzzy numbers can be used in order to achieve an evaluation matrix. The prioritization method can be developed using the fuzzy method. Therefore, it is proposed that a fuzzy ELECTRE method be used to increase the accuracy of the results in future research.

The results of the presented questionnaire which was used to determine the importance and priority of criteria and alternatives, in order to establish a decision hierarchical structure, show that among the studied criteria and alternatives, only five criteria and alternatives have a group mean more than 7, which is considered when establishing a decision hierarchical chart and providing pairwise comparison questionnaires.

Furthermore, the following results were obtained using pairwise comparisons questionnaires, mean of experts' opinion, group pairwise comparison matrix of importance, and priority of criteria and alternatives (Fig. 2, 3). According to Fig. 2, the criteria of proportion and adaptation to environment (C7) and time (C2) have the highest and lowest importance, respectively. The criterion of proportion and adaptation to the environment (C7), with the importance level of 33.3 %, and destruction of resources, human and social damage (C_{16}), with 31.1 %, were placed in first and second position, respectively. This indicates that experts are more concerned about environmental issues and challenges raised in environmental degradation. These tables also represent the priority of alternatives to each criterion (Fig. 3). As seen in these tables, selected alternatives will differ according to each criterion.

Therefore, to select alternatives based on criteria set and rank their priority, a combination was made of the decision matrix generated by the ELECTRE model, and the priorities of the alternatives were established based on the criteria set. Finally, the AHP model was used in order to rank final alternatives.

According to the results of the prioritization of alternatives, it can be said that through vegetation cover development and reclamation (A_{23}), prevention of unsuitable land use changes (A_{18}), and modification of groundwater harvesting (A_{31}), the desertification phenomenon can be controlled in Khezr Abad region. Finally, in order to reclaim disturbed land and avoid destruction of areas at risk, it is recommended that de-desertification projects in Khezr Abad region be focused on these alternatives.

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