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Assessment of combating-desertification strategies using the linear assignment method

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Abstract. Nowadays desertification, as a global problem, affects many countries in the world, especially developing countries like Iran. With respect to increasing importance of desertification and its complexity, the necessity of attention to the optimal combating-desertification alternatives is essential. Selecting appropriate strategies according to all effective criteria to combat the desertification process can be useful in rehabilitating degraded lands and avoiding degradation in vulnerable fields. This study provides systematic and optimal strategies of combating desertification by use of a group decision-making model. To this end, the preferences of indexes were obtained through using the Delphi model, within the framework of multi-attribute decision making (MADM). Then, priorities of strategies were evaluated by using linear assignment (LA) method. According to the results, the strategies to prevent improper change of land use (A_{18}), development and reclamation of plant cover (A_{23}), and control overcharging of groundwater resources (A_{31}) were identified as the most important strategies for combating desertification in this study area. Therefore, it is suggested that the aforementioned ranking results be considered in projects which control and reduce the effects of desertification and rehabilitate degraded lands.

1 Introduction

Desertification is a significant global environmental and the socioeconomic problem in the world (Miao et al., 2015). Desertification is defined as a process of land degradation in arid, semi-arid and sub-humid areas due to various factors including climatic variations and human activities (Barbero-Sierra et al., 2015). Land degradation and its vicious form in arid and semi-arid lands, desertification, are still widespread – jeopardizing livelihoods and sustainable development (Fleskens and Stringer, 2014). They affect vulnerable populations and fragile ecosystems with irreversible outcomes (Bisaro et al., 2014). According to the United Nations Conference on Desertification (UNCOD), the desertification process threatens more than 785 million people living in arid regions. Of this number, 60 to 100 million people are affected by this phenomenon directly due to the loss of land fertility and other desertification processes (Meshkat, 1998). There are 100 million hectares in Iran facing desertification, especially wind erosion, water erosion and physicochemical destruction (Forest, Rangeland and Watershed Institute, 2005). Strong communication between scientific knowledge and stakeholders is needed to slow down and reverse the impacts of land degradation on drylands (Barbero-Sierra et al., 2015).

Combating desertification includes activities that are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development, aimed at the (i) prevention and/or reduction of land degradation, (ii) rehabilitation of partly degraded land and (iii) reclamation of desertified land (Law Office of Environment and Parliamentary Affairs, 2004). By taking this framework into account, this study tries to present a systematic method for providing effective solutions among the several solutions based on different desertification criteria. Therefore, in order to achieve this goal, decision-making models and the linear assignment (LA) method were used to rank desertification alternatives.

Managing desert ecosystems consist of various managements to control desertification phenomenon and minimize economic, social and environmental loss. Making decisions about the management of desert areas becomes a complex process due to the existence of various indexes and various criteria for decision-making in such areas. There are several methods for managing desert regions, and each has different preferences for environmental, social, political, economic and organizational issues. Among these different methods, multi-attribute decision making (MADM) can provide the best answers in comparison to others. The purpose of this study, by considering limitation of inputs, is to assess desertification strategies to achieve the optimal strategies in the framework of sustainable management of desert area. To achieve this goal, the LA method, which is one kind of concordance method, was used in the framework of MADM to rank combating-desertification strategies. This method has a simple algorithm that can engage simultaneously a large number of quantitative and qualitative criteria in the decision-making process. Additionally, in different intervals of time and place, it is also capable of changing the input data and providing new assessments according to this change. Therefore, comparative studies would be easy to do (Asgharpour, 1999).

LA has two advantages: first being descriptive and second being easy to understand. Therefore, it has been applied in various fields of science (Bernardo and Blin, 1977). Some of these studies include assessing environmental sustainability (Hosseinzadeh et al., 2011), assessing and ranking risks (Sayadi et al., 2011), monitoring sensitivity of desertification (Symeonakis et al., 2014), footprint of research in desertification management (Miao et al., 2015), characterization and interaction of driving factors in desertification (Xu and Zhang, 2014), identifying susceptible areas toward desertification (Vieira et al., 2015), evaluation of soil fertility in the succession of karst rocky desertification (Xie et al., 2014), assessing environmental sensitivity of areas toward desertification (Sobhand and Khosravi, 2015), financial assessment of companies (Mohammadi, 2011), assessing strategies of water supply (Mianabadi and Afshar, 2008), zoning watersheds (Ramesht and Arabameri, 2012), assigning water resources in order to minimize the energy consumption (Joung et al., 2012), programming of robots (Ji et al., 1992), programming the dispatch of helicopters in emergency missions (Celi, 2007) and so on and so forth.

By studying the research literature using decision models to provide optimal strategies in desert management is limited to research of Grau et al. (2010), Sadeghiravesh et al. (2010, 2013, 2014, 2016) and Sepehr and Peroyan (2011). In order to select the optimal strategies for providing an integrated plan to control erosion and desertification, Grau used three decision models in his research: Elimination and Choice Expressing Reality (ELECTRE), analytical hierarchy process (AHP) and Preference Ranking Organization Method For Enrichment Evaluation (PROMETHEE) (Grau et al., 2010). The results indicate the high efficiency of these models to provide an optimal strategy of desertification. Due to the use of complex methods in each model, the results were largely the same. Sadeghiravesh et al. prioritize the strategies in the Khezrabad region by using the following models: AHP (Sadeghiravesh et al., 2010), ELECTRE (Sadeghiravesh et al., 2014), weighted sum model (WSM) (Sadeghiravesh and Zehtabian, 2013), BORDA (Sadeghiravesh, 2014), PERMUTATION (Sadeghiravesh, 2013), and PROMETHEE (Sadeghiravesh et al., 2016). The results of these studies are the same and largely similar to the results of previous research. Sepehr and Peroyan zoned the vulnerability of desertification in the ecosystems of the Khorasan Razavi Province and evaluated these strategies to combat desertification (Sepehr and Peroyan, 2011).

All in all, determining effective combating-desertification alternatives and criteria is essential for achieving efficient projects to combat desertification. Hence, this research uses the linear assignment method to objectively select the optimal combating-desertification alternatives based on the results of interviews with experts in the Khezrabad region in Yazd province, Iran, as the case study.

2 Material and methods

2.1 Study area

The Khezrabad region in Yazd province, central Iran, was chosen 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′ E in longitude and from 31°45′ to 32°15′ N in latitude and covers an area of about 78 180 ha (Fig. 1). The climate of the study area is cold and arid, based on the Amberje climate classification method (Sadeghiravesh, 2008). About 12 930 ha (16 %) of the region is hilly, and a sand-dune area[1], which is a part of the Ashkezar Great Erg[2], is located in the northern part of the study area. About 9022 ha (12 %) of the area consists of bare lands, clay plain and desert pavement[3] (Sadeghiravesh, 2008; Kazemi Nejad, 1996). About 1995 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.

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

[2] 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.

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

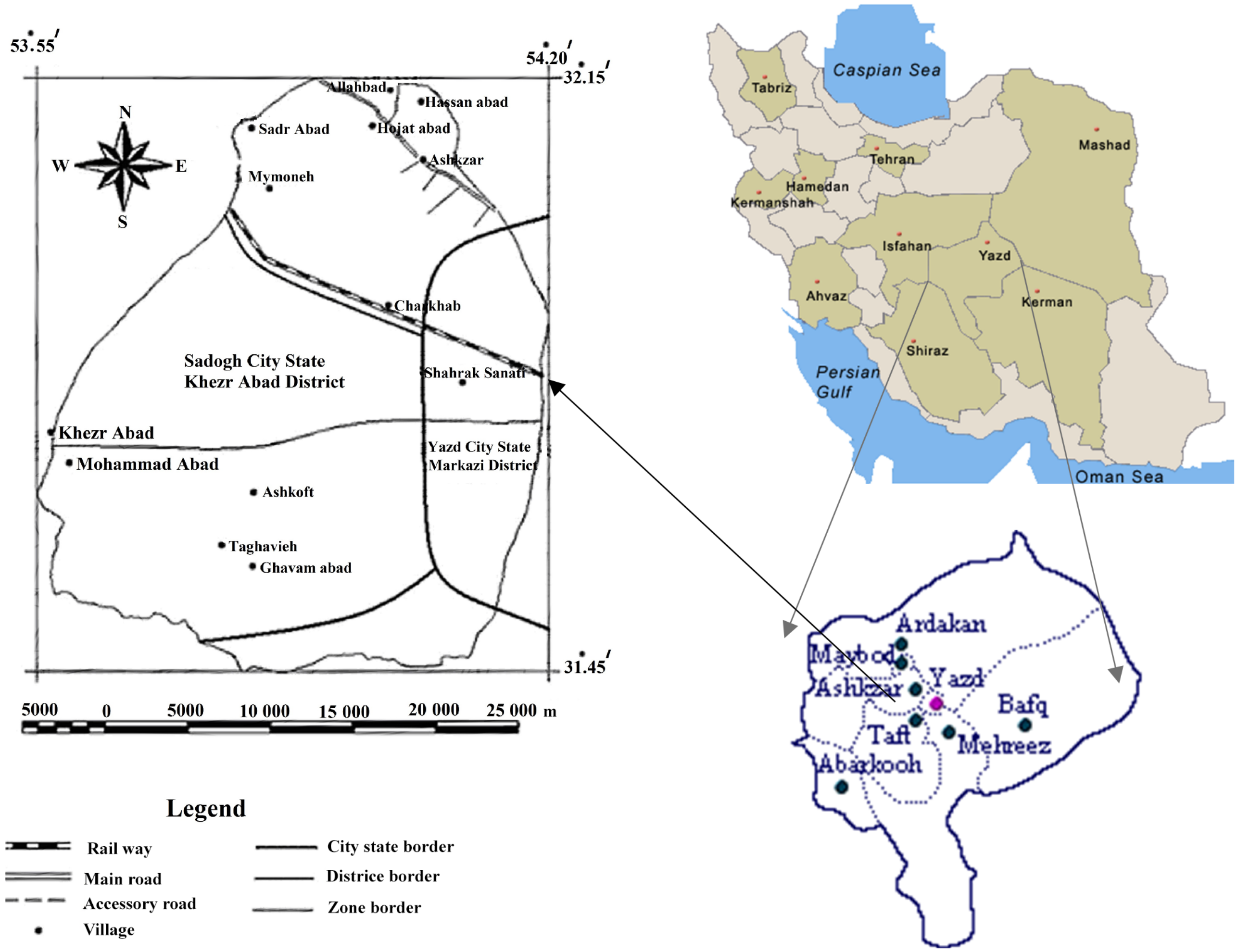


Figure 1. Location of the study area.

2.2 Methodology

Linear assignment is one of the most important methods of MADM and a subset of concordance methods. LA can help decision makers choose the best option by combining qualitative and quantitative indexes and providing appropriate weighting for each criterion. The output of this model is a collection of ranks, so it provides the required coordination in the most suitable way. In this method, given choices of moot point are ranked according to their scores on each index and the final ranking of the alternatives will be characterized through linear compensation processing (for every possible interaction between indexes) (Asgharpour, 1999). Based on the property simplex solution space of LA, the optimum solution is extracted in a convex space simplex and by considering all the arrangements implicitly. Moreover, the compensation property of the indexes is obtained from exchange between ranks and options (Pomerol and Romero, 2000); however, the weight vector of indexes has been obtained through expert opinion and the Delphi model.

2.2.1 Selection of criteria and effective strategies

Selecting criteria and alternatives can be done individually according to expert experience, resources, field studies and the Delphi method. To this aim, the structured questionnaire, in two parts including 16 criteria and 40 alternatives, was distributed among experts familiar with the study area. The experts were asked to rate effective criteria and alternatives between 0 and 9. Finally, arithmetical mean was used to calculate the mean of obtained results, and mean values were calculated. In this case, if the mean value was less than 7 ($\overline{X}<7$), related criteria and alternatives were removed; if the mean value was more or equal to 7 ($\overline{X} \geq 7$), related criteria and alternatives were used as effective criteria (Azar and Rajabzadeh, 2002; Azar and Memariani, 2003). Tables 1 and 8 show the recommended alternatives, offering criteria.

Table 1. The criteria and their importance mean according to the group.

Code	C_1	C_2	C_3	C_4	C_5	C_6
Criteria	Expense–benefit	Time	Participation of local communities	Beauty of landscape	Access to the technologies and scientific methods and devices	Access to the related expert
Code	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Criteria	Proportion and adaptation to the environment (sustainability)	Traditional management and local knowledge	Democratic government authority in combating-desertification projects	Oil income of government	Temporary management of projects	The problems resulted from innovation and method changes
Code	C_{13}	C_{14}	C_{15}	C_{16}		
Criteria	Indolence state administrative systems	Social and political pressures	Emergency issues related to desertification occurrence	Destruction of resources, human and social damages		

Table 2. Importance and priority degree according to the nine-point Saaty scale.

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	

2.2.2 Calculation of local priority of criteria and alternatives and establishment of group pairwise comparison matrix

In order to achieve local priority, the structured questionnaire was designed based on literature and the nine-point Saaty scale: 1 (least important) to 9 (most important). They were used to measure the relative importance of criteria and priority of combating-desertification alternatives (Table 2).

The questionnaire was distributed among experts familiar with the study area. Using geometric mean and assumption of expert's opinion (considering all opinions have same value), pairwise comparisons matrixes were obtained according to Eq. (1) and formed in a group format (Table 3).

$$\overline{a}_{ij} = \left(\pi_{k=1}^{N} a_{ij}^{k}\right)^{\frac{1}{N}} \tag{1}$$

Table 3. Pairwise comparisons matrix.

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

a_{ij} is the preference of i criteria to j criteria.

In this equation, $a_{ij}k$ is the component of k expert to comparison i and j. So, $\overline{a}_{ij}$ (geometric mean) for all corresponding components is obtained by Eq. (1) (Azar and Rajabzadeh, 2002; Ghodsipour, 2002).

2.2.3 Computation of the priorities based on group pairwise comparison tables

At this stage, the data of group pairwise comparison matrixes were imported in EC software to evaluate criterion, importance and alternative priorities to each criterion (Godsipour, 2002). After normalization by using Eq. (2) importance and priorities percent were showed as bar graphs using the harmonic mean method or average of each level of normalized matrix (Tables 5 and 6).

$$\overline{r}_{ij} = \frac{\overline{a}_{ij}}{\sum_{i=1}\overline{a}_{ij}} \tag{2}$$

In this equation, $\overline{r}_{ij}$ is the normal component, $\overline{a}_{ij}$ is the group pairwise comparison component of i to j and $\Sigma\overline{a}_{ij}$ is the total column of group pairwise comparisons.

Table 4. Normalized decision matrix.

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

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

2.2.4 Formation of normalized decision matrix

The weight values of criterion importance (W_j) and alternative priorities (P_{ij}) are considered in the form of a decision matrix based on any criteria (Table 4).

2.2.5 Ranking each option for each index

After forming the decision-making matrix, we attempted to rank the alternatives (A_i) for each criteria (C_i) with respect to the increasing or decreasing trends and $n \times m$ matrix framework (Table 7).

2.2.6 Forming two-dimensional gamma ($\boldsymbol{\gamma}$) matrix

A two-dimensional ($\boldsymbol{\gamma}$) matrix (assignment matrix) is formed according to the weight vector of the estimated criteria of group pairwise comparison. This matrix is a square matrix ($\boldsymbol{\gamma}_{m\times m}$) which has element i in its row and element k in its column. Matrix elements include the total weight of indexes, in which the alternative of i has rank k. The ($\boldsymbol{\gamma}$) matrix is a assignment matrix, so the optimal solution can be obtained by any kind of assignment methods such as the shipping method, Hungarian method, grid method and 1–0 linear programming method. The most common method for solving the LA is the assignment programming method (Pomerol and Romero, 2000).

2.2.7 Calculating the final rank for each alternative ($\boldsymbol{A_i}$)

The final ranking/optimal solution of alternatives is obtained by linear programming method and through the following model:

$$\text{maximize} \sum_{i=1}^{m}\sum_{k=1}^{m} \boldsymbol{\gamma}_{ik}\, h_{ik}, \tag{3}$$

$$\text{subject to} \sum_{k=1}^{m} h_{ik} = 1; \quad i = 1,2,3,\ldots,m, \tag{4}$$

$$\sum_{i=1}^{m} h_{ik} = 1be; \quad k = 1,2,3,\ldots,m; \quad h_{ik}\begin{cases} =1 \\ =0 \end{cases}. \tag{5}$$

After solving the linear programming model, a square matrix ($\mathbf{H}_{m\times m}$) is considered where A_i is given the final k rank ($h_{ik}=1$); otherwise $h_{ik}=0$ (Burkard and Qela, 1999; Liu, 2000)

The obvious feature of this method is a simple ranking for alternatives that caused exchanged among indexes and have no complex calculations. Also, in this method there is no need for the unification scale (Saaty and Vargas, 2006; Asgharpour, 1999). Meanwhile, other methods such as MADM need both alternatives and indexes for calculating, but ranking process of LA can be done without an alternative (Tajoddini, 2003).

3 Results and discussion

In the process of assessing combating-desertification alternatives in the study area, the Delphi method and questionnaire were used to identify the main criteria and alternatives among 16 criteria and 40 combating-desertification alternatives and establishing hierarchical structure (Saaty, 1995) according to the group format. Tables 8 and 9 show the average of alternative priority and criterion importance, respectively.

The obtained results of presented questionnaire (to determine importance and priority of criteria and alternatives to establish decision hierarchical structure) show only criteria and alternatives with a group mean larger than 7. This considered establishing decision hierarchical chart and providing pairwise comparisons questionnaires. Figure 2 show hierarchical decision structure based on effective criteria and alternatives to combat desertification.

3.1 Calculating relative weight of criteria and alternatives and formatting the group decision matrix

In order to estimate the relative weight or priority of criteria and alternatives, a pairwise comparison questionnaire was prepared and distributed among the experts. The group pairwise comparison matrixes of criterion importance and alternative priorities to each criterion were formed by obtaining expert opinions and combining their ideas by geometric mean. To prevent the prolongation of the word, just matrixes of criterion importance (Table 10) and alternative priorities to each criteria calculated by this method are presented.

Matrix values of criterion importance and alternative priorities (Table 10) were entered into EC software based on each criterion importance of combating-desertification criteria. Alternatives were obtained in a group format. In addition, graphs were prepared based on percentage using normalization and harmonic mean (Table 11).

Table 5. Comparison of proposed criterion importance to access the goal.

Criterion	Preference degree
C_7	33.3
C_{16}	31.3
C_6	15.7
C_5	11
C_2	8.9

Inconsistency ratio=0.01

Table 6. Comparison of alternative preference according to the criteria of proportion and adaptation to the environment.

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

Table 7. Matrix ranking of each option against each index.

Criteria (C) ► Rank (A) ▼	C_1	C_2	C_3	…	C_n
First	A_{11}	A_{12}	A_{13}	…	A_{1n}
Second	A_{21}	A_{22}	A_{23}	…	A_{2n}
Third	A_{31}	A_{32}	A_{33}	…	A_{3n}
…				…	
…				…	
m	A_{m1}	A_{m2}	A_{m3}	…	A_{mn}

In this matrix, m is the number of choices or alternatives, n is the number of criteria, C is the title of criteria and a_{ij} is the each alternative in relation to related criteria.

Considering these graphs, one can observe that the alternatives are different based on each criterion. Therefore, the decision-making matrix of optimal combating-desertification alternatives according to the group (Table 12) was formed to select final alternatives and classification of their priorities in the general framework of MADM (Table 4).

3.2 Ranking each option for each index

After forming the decision-making matrix, we attempted to rank the alternatives (A_i) for each criteria (C_i) in a 5×5 matrix in which the rows represent rank and columns represent the index (Table 13). The decision matrix of combating-desertification alternatives has an increasing trend, which means the allocated number of each alternative is more than the number of each criterion, so that alternative is more desirable than the others.

3.3 Forming $\gamma_{5\times5}$ matrix according to criterion weights (W)

At this stage a 5×5 γ matrix is formed, and it was estimated by the sum of index weights in which the alternative of i has rank k. As mentioned, the weight of each index was calculated by surveying experts and based on the Delphi method (Table 14).

The γ matrix is an assignment matrix, and the optimal answer can be obtained by any of assignment methods. The most common method for solving the linear assignment method is linear programming.

3.4 Ranking alternatives

For final ranking of alternatives, linear programming was used (Eqs. 1 to 3), and a scoring table of options or optimal matrix was formed (Table 11). Since the decision variable contains 0 and 1 value, the output of this program is provided only based on the number 1 in Table 15. Table 16 was formed according to Table 15.

Based on Table 17, the preference of alternatives was obtained as $A_{18} > A_{23} > A_{31} > A_{33} > A_{20}$. After evaluating all alternatives, A_{18} considered to be the best one.

4 Discussion

In this study a new method was presented to rank combating-desertification alternative priority. The results of final prioritization of alternatives using LA method were similar to the results of the following methods: AHP (Sadeghiravesh et al., 2010), TOPSIS (Ivani and Sofi, 2014), ELECTRE (Sadeghiravesh et al., 2014) and WSM (Sadeghiravesh and Zehtabian, 2013). This means alternatives A_{18}, A_{23} and A_{31} were ranked, respectively, first to third. It should be men-

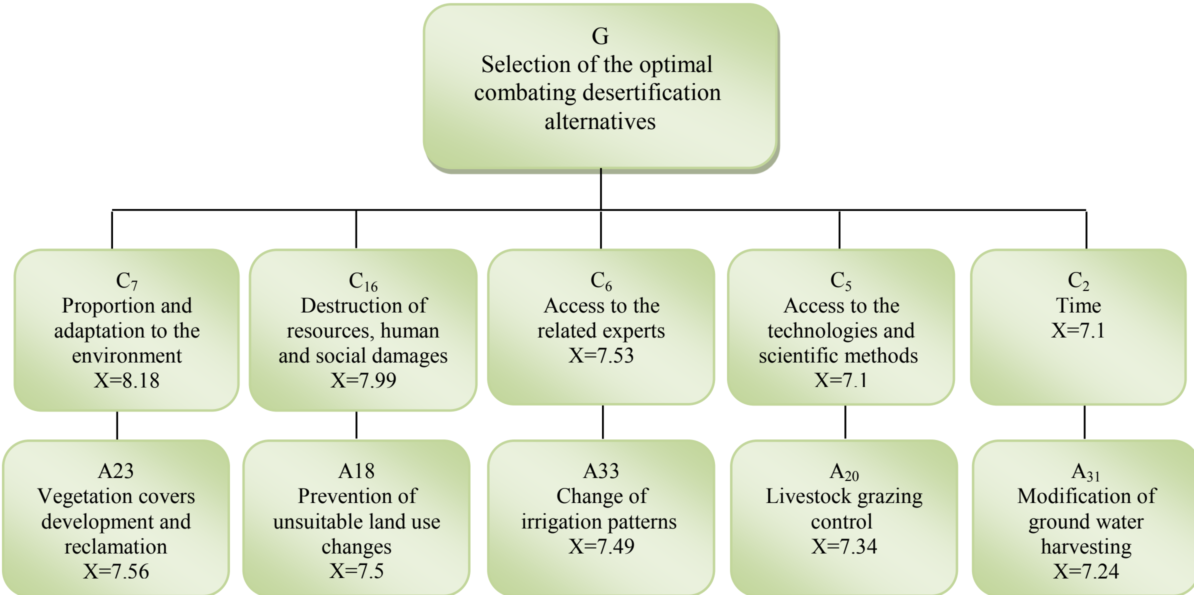


Figure 2. Hierarchical decision structure to select optimal combating-desertification alternatives in study area.

Table 8. The criteria importance mean according to the group.

Code	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
Average values	5.38	7.1	5.78	5.1	7.1	7.53	8.15	5.23	5.28	5.72	2.39	2.84	2.29	5.35	6.34	7.99

tioned, that the LA method has the limitation of ignoring decision makers fuzzy judgment as well as aforementioned methods. Additionally, some criteria have qualitative or unknown structures that cannot be accurately measured. In such cases, fuzzy numbers can be used in order to achieve evaluation matrix, and the prioritization method can be developed using the fuzzy method. Another disadvantage of the LA method is regarding the amount of data and considering only the data ranks. Therefore, large amounts of data are lost and achieving high-accuracy results would not be possible (Mohammadi, 2011). Consequently, it is better to not use rating models such as ELECTRE and LA when accurate amounts of data are available. The following results were obtained using pairwise comparisons questionnaires, the mean of expert opinions, group pairwise comparisons matrix of importance and priority of criteria and alternatives. According to the decision matrix's table of optimal combating-desertification alternatives (Table 12), criteria of proportion and adaptation to environment (C_7) and time (C_2) have the highest and lowest importance, respectively. Criterion proportion and adaptation to the environment (C_7) with an importance degree of 33.6 % and destruction of resources, human and social damages (C_{16}) with 30.7 % were placed in first and second order, respectively. This indicates that experts are more concerned about environmental issues, and challenges rose in environmental degradation. Also, these tables represent alternative priorities to each criterion. As is taken from the table, selected alternatives will be different according to each criterion. Therefore, the selection of final alternatives and ranking of their priority combinations were conducted on decision matrix by LA model; additionally, alternative priorities were formed based on a set of criteria. According to the results of the final alternative prioritization and by considering all the alternatives, execution of prevention of unsuitable land use changes (A_{18}), vegetation cover development and reclamation (A_{23}) and modification of groundwater harvesting (A_{31}), the desertification process can be stopped and the degraded lands can be rehabilitated. Therefore, in the study area, land use changes are mainly caused by increasing population, unemployment, growth of industry and increasing urbanization. To illustrate, land use changes have largely happened in recent years because of pressure of drought and industrial growth which lead to conversion of pastures into farms and gardens. As a consequence, enormous numbers of deep and semi-deep motorized wells have been installed in the study area. Rangelands consist of 6 to 15 % of the case area, which is strongly influenced by human activities in terms of cutting brush and livestock overgrazing, so that 40 to 50 % of plant cover are destroyed. Irrigation in agricultural lands is mostly flooding with outdoor pools and outdoor

Table 9. The recommended alternatives to combat desertification and their priority according to the groups.

Code	Alternative	Value
A_1	Reducing population growth rates	5
A_2	Poverty alleviation	5.68
A_3	Establishment and development of rural organizations	5.35
A_4	Increasing employment	6.7
A_5	Increasing participation of local community and supporting NGOs	6.1
A_6	Application of local forces and technology in projects (local knowledge)	6.56
A_7	Training people in utilization of new methods and use of new knowledge for optimal use of resources	6.47
A_8	Approval, promotion and implementation of laws and adaptation punishments with the crime	5.73
A_9	Providing needs of local residents	5.89
A_{10}	Modification of unsustainable consumption patterns, changing and improving people's livelihood patterns	5.6
A_{11}	Considering the role of women and youth in combating-desertification process	4.5
A_{12}	Organization of urban areas and prevent migration	5.23
A_{13}	Coordination between responsible agencies and organizations in combating-desertification and environmental protection	6.86
A_{14}	Raising the literacy rate	4.8
A_{15}	Development of desert ecotourism	5.32
A_{16}	Multi-utilization from desert instead of mono-utilization	5.27
A_{17}	Allocation combating-desertification issue to the private sector	3.79
A_{18}	Prevention of unsuitable land use changes	7.5
A_{19}	Mapping land use planning and determination of desert and salt desert boundaries	6.44
A_{20}	Livestock grazing control	7.34
A_{21}	Forage production and increasing economic potential of sustainable husbandry	6.6
A_{22}	Prevention of plant cutting	6.46
A_{23}	Vegetation cover development and reclamation	7.56
A_{24}	Protection of *Haloxylon* spp.	6.76
A_{25}	Protection of gravel surfaces (Reg)	6.45
A_{26}	Prevention and reduction in heavy agricultural and industrial machinery traffic	5.57
A_{27}	Create living and non-living wind break for soil conservation	6.86
A_{28}	Improvement of soil texture	4.66
A_{29}	Modification of crop rotation and follow methods	5.42
A_{30}	Modification of ploughing, fertilization and spraying methods	5.1
A_{31}	Modification of groundwater harvesting	7.24
A_{32}	Reduction in water consumption (water-optimal consumption in farms)	6.6
A_{33}	Change of irrigation patterns	7.49
A_{34}	Changing traditional irrigation systems with low to modern systems with high efficiency	6.53
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)	6.64
A_{36}	Groundwater feed	6.08
A_{37}	Construction of flood broadcast networks and the use of its alluviums	5.3
A_{38}	Creation of artificial precipitation to feed aquifers	3.47
A_{39}	Promotion of greenhouse cultivation	6.2
A_{40}	Introduction of new plant varieties, resistant to drought and dehydration stress by genetic engineering	6

Table 10. Pairwise comparisons matrix of the criterion importance to complete the goal of "offering optimal combating-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

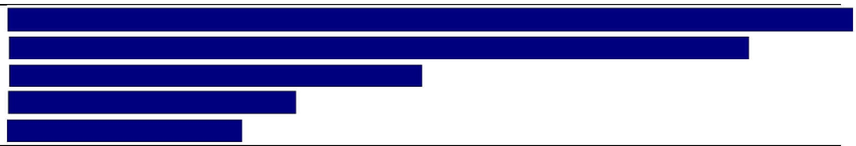
streams with large pores in bed; therefore, more than 50 % of water's consumption is wasted and the efficiency of irrigation and transmission is estimated to be less than 40 %.

5 Conclusions

In this research the LA method was used to give optimum alternatives for combating desertification. In accordance with the results, prevention of unsuitable land use changes was estimated as the most important strategy in the study area. Additionally, other alternatives such as vegetation cover development and reclamation and balancing charging of groundwater resources were were considered subsequent priorities.

Table 11. Comparison of proposed criterion importance to access the goal.

Criterion	Preference degree
C_7	33.3
C_{16}	31.3
C_6	15.7
C_5	11
C_2	8.9



Inconsistency ratio=0.01

Table 12. Decision matrix of optimal combating-desertification alternatives according to group.

Criterion importance (C) ▶ / Alternatives priority (A) ▼	C_2	C_5	C_6	C_{16}	C_7
	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

Table 13. Matrix of alternative ranking.

Criteria (C) ▶ / Rank (A) ▼	C_7	C_{16}	C_6	C_5	C_2
First	A_{18}	A_{18}	A_{23}	A_{33}	A_{23}
Second	A_{23}	A_{20}	A_{33}	A_{23}	A_{20}
Third	A_{31}	A_{31}	A_{18}	A_{20}	A_{18}
Fourth	A_{33}	A_{23}	A_{31}	A_{18}	A_{31}
Fifth	A_{20}	A_{33}	A_{20}	A_{31}	A_{33}

Table 14. The matrix of number time weight of ranking options.

Rank (C) ▶ / Alternative priority (A) ▼	First	Second	Third	Fourth	Fifth
A_{23}	0.2468	0.446	0	0.3074	0
A_{18}	0.6439	0	0.2468	0.1095	0
A_{33}	0.1095	0.1576	0	0.3365	0.3966
A_{20}	0	0.3966	0.1095	0	0.4941
A_{31}	0	0	0.6439	0.2468	0.1095

Table 15. The options scoring.

$$^{*}=H \left| \begin{array}{ccccc} 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 \end{array} \right.$$

The optimal objective function = 2.6245.

Table 16. The matrix of options optical order.

$$A=^{*}\times H \left| \begin{array}{ccccc} 0 & A_{18} & 0 & 0 & 0 \\ A_{23} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & A_{31} \\ 0 & 0 & 0 & 0 & A_{33} \\ 0 & 0 & A_{33} & 0 & 0 \end{array} \right.$$

Hence, in the framework of macro-strategies executive offers are recommended in the following:

– taking serious spatial planning and estimating ecological potential at national, regional and local levels and adapting the applications to the land potential

– avoiding land use changes in poor rangelands with low fertility

– avoid the development of industries in sensitive and fragile regions

– in terms of development and reclamation of vegetation, it is better to use endemic and resistant species and pressurized irrigation systems

– balance the number of livestock and pasture capacity

– avoid grazing off-season in desert rangelands (early and late grazing) due to degradation of poor vegetation.

The results of this research can be used in future investments aiming to obtain a sustainable development, so that the marginal ecosystems and investments in arid and semi-arid region will be protected. Allocated investments for arid

Table 17. The options ranking.

A_{18}	A_{23}	A_{31}	A_{33}	A_{20}

regions are limited; thus, arid land managers should take the results of this research into account for preventing any waste of those limited investments.

Finally, it is recommended that all combating-desertification projects in the study area be done based on all aforementioned alternatives. In this case, less investment would be wasted and the efficiency of such rehabilitation projects may increase. The results of this study will allow desert managers to apply limited investment and facilities in efficient ways to control the process of desertification. Hence, we can achieve better results and avoid wasting national investments.

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