Assessment of combating desertification strategies using the linear assignment method

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Abstract

Select appropriate strategies according to all effective criteria in combating desertification process can be so useful in controlling and rehabilitation of degraded lands, and avoid degradation in vulnerable fields. This study provides systematic and optimal strategies of combating desertification by group decision-making model. To this end, in the framework of Multi Attribute Decision Making (MADM) and by using Delphi model (Delphi), the preferences of indexes were obtained. 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 (A18), development and reclamation of plant cover (A23) and adjustment for harvesting from groundwater sources (A31), respectively were identified as the most important strategies for combating desertification in this study area. Therefore, it was suggested to consider ranking results in projects which controls and reduces the effects of desertification and rehabilitates degraded lands.

Keywords: desertification, Multi Attribute Decision Making, Linear Assignment model, pair wise comparisons.

1Introduction

Desertification is a type of land degradation in which a relatively dry land region becomes increasingly arid, typically losing its bodies of water as well as vegetation and wildlife. It is caused by a variety of factors, such as climate change and human activities. Desertification is a significant global ecological and environmental problem. According to United Nations Conference on Desertification (UNCOD), desertification process threatens more than 785 million people living in the arid regions. Of this number, 60 to 100 million people are affected directly due to the loss of land fertility and others desertification processes (Meshkat, 1998). In Iran 100 million hectares are affected by desertification processes especially wind erosion, water erosion and physicochemical (Forest, Rangeland and Watershed Institute, 2005).

"combating 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 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). Based on this framework, this paper tries to present a systematic method to provide effective solutions among the several solutions based on different desertification criterion. Therefore, in order to achieve this goal in the context of decision-making models and linear assignment (LA) method were used to rank combat to desertification alternatives.

Managing desert ecosystems is a collection of various managements to optimize control of desertification phenomenon and minimize the loss of economy, society and environment. Making decision in management of desert areas is a complex issue due to various indexes and various criterions for decision in such areas. There are several ways to achieve a specific purpose since each has different preferences for the different issues of environmental, social, political and economical organization. These requirements lead to the use of Multi Attribute Decision Making (MADM) which its purpose is to choose the best answer among the different solutions. The purpose of this study while considering the 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 with framework of MADM, using Linear Assignment (LA) were considered to rank combating desertification strategies which is a kind of Concordance Methods. This method having a simple algorithm has this ability to engage simultaneously a large number of quantitative and qualitative criteria in the decision process. In different intervals of time and place, it is also capable to change the input data and provide new assessment according to this change. Therefore comparative studies are easy to do (Asgharpour, 1999).

According to using descriptive data instead of principal data in this method, so it is easy to understand and has been used in various fields of science (Bernardo and Blin, 1977). Some of these studies including assessment of environmental sustainability (Hosseinzadeh et al., 2011), Assessing and ranking risks (Sayadi et al, 2011), Monitoring sensitivity to desertification (Symeonakis et al., 2014), footprint of research in desertification management (Miao et al., 2015), Characterization and interaction of driving factors in desertification (Xu et al., 2014), Identifying areas susceptible to desertification (Vieira et al., 2015), Evaluation of soil fertility in thesuccession of karst rocky desertification (Xie et al., 2014), Assessing Environmental Sensitivity Areas to Desertification (Sobhand and Khosravi, 2015), Financial assessment of companies (Mohammadi, 2011), assessment of strategies of water supply (Mianabadi and Afshar, 2008), Zoning watersheds (Ramesht and Arabameri, 2012), Assignment of resource in order to minimize the energy consumption (Joung et al, 2012), Programming of robots (Ji et al, 1992), Programming for dispatching helicopter in emergency missions (Celi, 2007) And so on. 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; ELECTRE, AHP and PROMETHEE (Grau et al, 2010). The results indicate the high efficiency of these models to provide optimal strategy of combating desertification, despite complex methods which are used in each model; the results were largely the same. Sadeghi ravesh prioritize the strategies in Khezr Abad region, by using the following models; AHP (Sadeghi ravesh et al, 2012), TOPSIS (Sadeghi ravesh et al, 2012), EECTER (Sadeghi ravesh et al, 2014) and FAHP (Sadeghi ravesh et al, 2015). The results of these studies are same and largely similar to the results of previous research.

2 Material and methods

2.1 Study area

In this research, Khezr Abad region in Yazd province (Central Iran) is located about 10 km west of Yazd. This region extends from 53° 55' to 54° 20' east in longitude and from 31° 45’ to 32° 15’ north in latitude, covering about 78180 ha area. The climate of this region is cold and arid based on Amberje climate classification method. About 12,930 ha (16.5%) of the region are hilly and the sand dune area (sandy desert with inselberges) which shows absolute typical condition of desertification in the study area, hence the following effective solution and optimum combating desertification alternatives are necessary.

2.2 Methodology

Linear Assignment is one of the most important methods of Multi Attribute Decision Making (MADM) and subset of Concordance Methods, which can help decision makers to choose the best option, due to 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 ranking according to their scores on each index, then the final ranking of the alternatives will be characterized through linear compensation process (for every possible interaction between indexes) (Asgharpour, 1999). Based on the property simplex solution space of Linear Assignment, while considering all the arrangements implicitly, the optimum solution in a convex space simplex is extracted. In addition, the compensation property of the indexes is obtained from exchange between rank and options (Pomerol and Romero, 2000).

Although the weight vector of indexes have been obtained through expert opinion and Delphi model:

2.2.1 Selection criteria and effective strategies

Selecting criteria and alternatives can be done individually according to expert experience, resources, and field studies or using Delphi method, distributed a structured questionnaire among experts familiar with the study area. 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 ($\overline{X}<7$), related criterion and alternative was removed and if the mean value was more or equal to 7 ($\overline{X}\geq 7$) related criterion and alternative was used as effective criteria (Azar and Rajabzadeh 2002; Azar and Memariani, 2003).

2.2.2 Calculate local priority of criteria and alternatives and establish group pairwise comparisons matrix

in order to achieve Local Priority, the structured questionnaire was designed based on literature and the nine-point Sa'aty scale, from 1(least important) to 9 (most important) were used to measure the relative importance of criteria and priority of combating desertification alternatives (Table 1).

The questionnaire was distributed among experts familiar with the study area. In continuation, using geometric mean and assumption of uniform expert's opinion, pairwise comparisons of each expert (Table 2) were composed according to Eq. 1; and pairwise comparisons were formed regarding to group.

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

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; Ghodsipour, 2002).

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

Score	Importance Degree	Priority Degree in Pair wise 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

Table 2. Pair wise comparisons matrix

A=	a_{11}	a_{12}	....	a_{1n}	$A=[a_{ij}]$ i,j =1,2 ,…,n
	a_{21}	a_{22}	....	a_{2n}	
	:	:	:	:	
	a_{n1}	a_{n2}	....	a_{nn}	

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

2.2.3 Compute the priorities based on group pair wise of comparisons tables

At this stage, the numbers of group pairwise comparisons matrix (values of criteria importance and alternatives priority to each criterion) were imported in EC software (Godsipour, 2002). After normalization by using Eq. 2, importance and priorities percent were showed as bar graphs using harmonic mean method or average of each level of normalized matrix (Tables 4 and 5).

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

In this equation:

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

ij ā = group pair wise comparison component of i to j

Σāij = total column of group pair wise comparisons

2.2.4 Formation of Normalized Decision Matrix (NDM)

At this stage, the weight values of criteria importance (Wj) and alternatives priority (Pij) is considered in the form of a decision matrix based on any criteria (Table 3).

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

Table 4. Comparison of proposed criteria 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 5. Comparison of alternatives 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

2.2.5 Ranking each option for each index

After forming the decision making matrix, attempted to rank the alternatives (Ai) for each criteria (Ci) with respect to the desirability of increasing or decreasing and with n×m matrix framework (Table 6).

Table 6. 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= the number of choices or alternatives, n= number of criteria, C= title of criteria, a_{ij}= each alternative in relation to related criteria

2.2.6 Forming two-dimensional matrix, Gamma (γ)

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

2.2.7 Calculating the final rank for each alternative (A_i)

At this stage the final ranking of alternatives or in other words the optimal solution is obtained by linear programming method and through the following model:

$$\text{Maximize}: \sum_{i=1}^{m} \sum_{k=1}^{m} \gamma_{ik} . h_{ik} \tag{3}$$

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

$$\sum_{i=1}^{m} h_{ik} = 1 be \quad ; k = 1,2,3,...,m \qquad (5)$$

$$h_{ik} \begin{cases} = 1 \\ = 0 \end{cases}$$

After solving the linear programming model, if h_{ik} be 1 a square matrix ($H_{m \times m}$) is considered so that A_i is given to the final rank ok K th. In others ways h_{ik}=0 (Burkard and Qela, 1999; Liu, 2000)

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

3Result and Discussion

3.1 Select criteria and alternatives regarding to group and establish decision hierarchical structure

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

3.2 Calculate relative weight of criteria and alternatives and format group decision matrix (DM)

In order to estimate the relative weight or priority of criteria and alternatives, pairwise comparisons questionnaire was prepared and distributed among the experts. In continuation, the group pair wise comparisons matrix of criteria importance to goal and alternatives priority to each criterion was formed by obtaining expert opinions and combining their ideas by geometric mean. To prevent the prolongation of the Word, just matrix of criteria importance is presented (Table 7), and alternatives priority to each criteria calculated by this method.

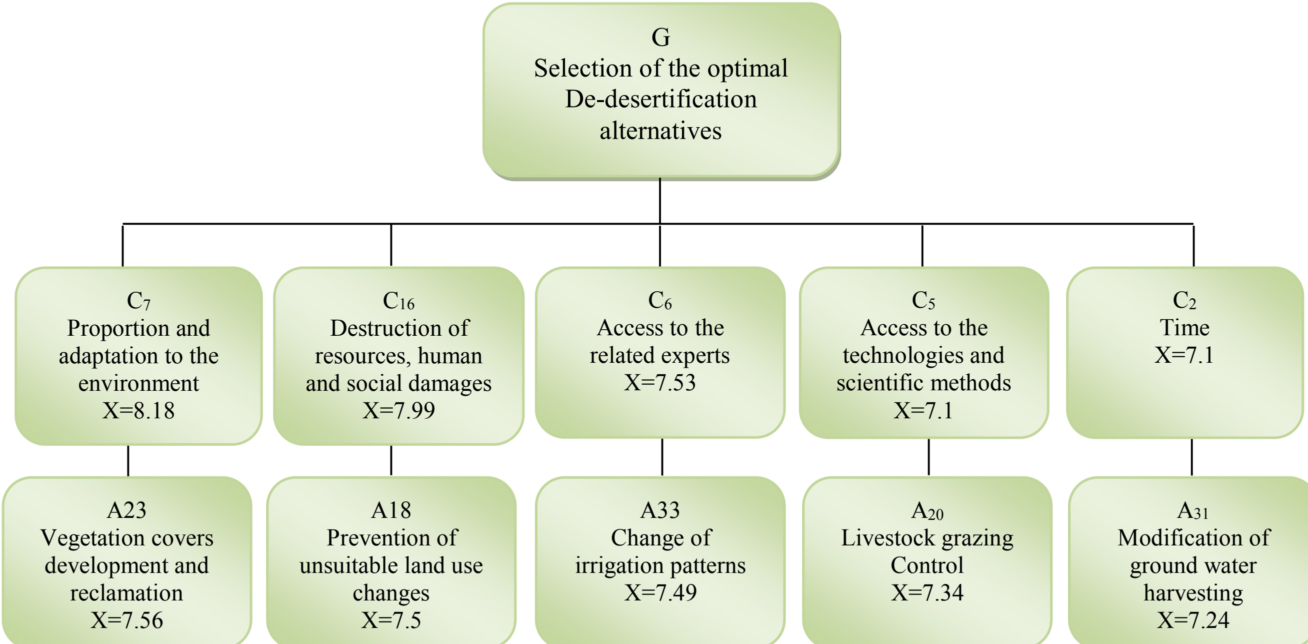

Figure 1. Hierarchical decision structure to select optimal combating desertification alternatives in study area

Table 7. Pairwise comparisons matrix of the criteria importance to access 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

In continuation, matrix values of criteria importance and alternatives priorities (Table7) were entered EC software based on each criterion, and importance and priority of combating desertification criteria and alternatives were obtained according to group in the study area as bar graphs based on percentage using normalization and harmonic mean (Table8).

Table 8. Comparison of proposed criteria 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

Considering these graphs, it is observed that the alternatives are different based on each criterion. Therefore, decision making matrix of optimal combating desertification alternatives according to the group (Table 9) was formed to select final alternatives and classification of their priorities, in general framework of MADM (Table 3).

Table 9. Decision matrix of optimal combating desertification alternatives according to group

Criteria importance (C) ► Alternatives priority (A) ▼	C2 0.0892	C5 0.1095	C6 0.1576	C16 0.3074	C7 0.3365
A23	0.2509	0.2387	0.2488	0.1805	0.2257
A18	0.1960	0.1635	0.1983	0.2383	0.2643
A33	0.1620	0.2565	0.2093	0.1510	0.1599
A20	0.2229	0.1762	0.1608	0.2209	0.1582
A31	0.1682	0.1633	0.1826	0.2092	0.1918

3.3 Ranking each option for each index

After forming the decision making matrix, attempted to rank the alternatives (Ai) for each criteria (Ci) in a 5×5 matrix which the rows represent rank and columns represent the index (Table10). Decision Matrix of combating desertification alternatives has increasing desirability, it means if the allocate number to each alternative priority associated with each criterion be more, then it represents the more priority of this alternative to achieve the goal, Therefore, in any criterion which gain the highest priority is the optimal alternative.

Table 10. 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}
Forth	A_{33}	A_{23}	A_{31}	A_{18}	A_{31}
Fifth	A_{20}	A_{33}	A_{20}	A_{31}	A_{33}

3.4 Forming $\gamma_{5\times5}$ matrix according to criteria weights (W)

At this stage a 5 × 5 gamma matrix is formed, Matrix was estimated by sum of indexes weights which the alternative of i has rank of k. As mentioned, the weight of each index was calculated by survey of experts and based on Delphi method (Table 11).

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

Table 11. The matrix of number time weight of ranking options

Rank (C) ► / Alternative Priority (A) ▼	First	Second	Third	Forth	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

3.5 Ranking alternatives

At this stage for final ranking of alternatives by using linear programming (Eq. 1 to 3) scoring table of options or optimal matrix was formed (Table 11). Since the decision variable contain zero and one values, so the output of this program is provided only based on the number 1 in Table 12 then according to this table, scoring table of options was formed (Table 13).

Table 12. The options scoring

$$*=H \begin{vmatrix} 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 \end{vmatrix}$$

The optimal objective function = 2.6245

→

Table 13. The matrix of options optical order

$$A=^{*}\times H \begin{vmatrix} 0 & A_{18} & 0 & 0 & 0 \\ A_{23} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & A_{31} \\ 0 & 0 & 0 & 0 & A_{33} \\ 0 & 0 & A_{33} & 0 & 0 \end{vmatrix}$$

Table 14. The options ranking

$$\rightarrow \quad \begin{vmatrix} A_{18} & A_{23} & A_{31} & A_{33} & A_{20} \end{vmatrix}$$

Based on Table 14, the preference of alternatives was obtained as $A_{18} > A_{23} > A_{31} > A_{33} > A_{20}$; and after evaluating the A_{18} alternative considered as the best one among all alternatives.

4 Discussions

In this study a new method was presented to rank combating desertification alternatives priority. The results of final prioritization of alternatives by using linear assignment method, was similar to the results of the following methods; AHP, TOPSIS, ELECTER and WSM. This means that alternatives A_{18}, A_{23} and A_{31}, were ranked respectively first to third. While

LA method as well as above mentioned methods, has the limitation of ignoring decision-makers fuzzy judgment. Also, some criteria have qualitative or unknown structure that cannot be accurately measured. In such case, fuzzy numbers can be used in order to achieve evaluation matrix. Prioritization method can be developed using fuzzy method. Another disadvantage of this method is: regardless the amount of data and just considering the data ranks, so large amounts of data is lost and achieving results with high accuracy is not possible (Mohammadi, 2011). Therefore try to do not use rating models as ELECTER and LA when accurate amounts of data are available. In general according to the results of final prioritization of alternatives, by implementation of following alternatives; Prevent improper land use change (A_{18}), Vegetation development and reclamation (A_{23}) And adjusting the withdrawal of groundwater resources (A_{31}); the desertification process can be prevented and the degraded lands can be restored. So it can be expressed in the study area, land use changes are resulting by: increasing population, unemployment, growth of industry and increase desire of urbanization. Land use changes is largely occurred in recent years by; conversion of pasture land to farm and garden on the effect of deep and semi-deep motorized wells, conversion of garden land to agricultural land on the effects of successive droughts, conversion of pasture lands to urban and industrial lands due to growth of industry and increasing urbanization. The density of range types is 6 to 15 percent which is strongly influenced by human activities in terms of cutting brush and livestock overgrazing so that 40 to 50 percent of plant cover are destroyed because of cutting brush for grazing, fuel and building materials. Irrigation in agricultural lands is mostly flooding with outdoor pools and outdoor streams with large pores in bed so that more than 50% of used water is wasted and the efficiency of irrigation and transmission is estimated less than 40 percent.

5 Conclusions

Desertification is the persistent degradation of dry land ecosystems by variations in climate and human activities. Home to a third of the human population in 2000, dry lands occupy nearly half of Earth's land area. More than 85% of Iran is occupied by arid, semi-arid and hyper-arid regions with 34 million ha of desert. So, the major part of the country is susceptible to desertification. Although the government has performed many projects to combat desertification in recent years, it seems that they are not adequate due to the country's extensive arid regions. The problem needs more attention in addition to effective cooperation in the national as well as international scene over the long-term.

In this research, the linear assignment method methods were used to give optimum alternatives in de-desertification. In accordance with the results, prevention of unsuitable land use changes was estimated as the most important strategy in region. And other alternatives of vegetation cover development and reclamation, modification of groundwater harvesting, respectively, were placed in subsequent priorities. So, in the framework of macro strategies, executive offers are recommended in following:

- Taking serious spatial planning and estimation of ecological potential at national, regional and local levels and adapting the applications to the land potential.
- Avoiding land use change from poor range land to farming land with low yield

- Avoid the development of industrial and workshop infrastructure in sensitive and fragile region of desert and marginal lands.

- In terms of development and reclamation of vegetation try to use endemic and resistant species and pressurized irrigation systems.

- Prevent degradation of *Haloxylon* habitats and effort taken towards their rehabilitation.

- Consider the balance of livestock and pasture capacity.

- Considering the suitability of livestock to the pastures. Try to reduce the number of goats in poor pasture because this animal is considered as an escalation potential factor in degrading rangelands.

- Avoid grazing off-season in desert rangelands (early and late grazing) because of degradation of poor vegetation.

- According to protect rangelands and support ranchers, used to produce and import forage increase the sustainable economic potential of ranches to stop them from residue grazing of farms and gardens and cutting brush which they do for night and winter livestock grazing, so acceleration of the degradation is prevented.

Finally, it is recommended to combating desertification schemes in the study area based on these alternatives is to prevent loss of limited investments and increase the efficiency of control, reclamation and construction plans. The results of this study will allow desert managers to apply limited investment and facilities in efficient ways, which are assigned to control the process of desertification. So either we can achieve better results or avoid wasting the national investments.

The results of this research can be used in future investments aiming at obtaining a sustainable development, so that the marginal ecosystems and investments in arid and semi-arid region will be protected. On the other hand, it will help the managers of desert lands to perform restricted facilities in susceptible areas to get better and suitable results and avoid investments wasting.

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