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Prediction of the vegetation management impacts on reduction of wind erosion risk in the southern parts of the Varamin Plain, Iran

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Abstract

Wind erosion is a major environmental issue affecting land resources and socio-economic settings in Iran. This paper outlines a study undertaken to provide a new tool to manage wind erosion from physical and economic perspectives. The southern part of the Varamin Plain in south of Tehran is used as a case study. The focus of this study is on exploring the economic and physical impacts of 16 vegetation-based scenarios for wind erosion management as well as conducting a trade-off analysis using the Multi-Criteria Decision Making (MCDM) technique. This involves developing a modeling system to assist decision makers in formulating scenarios, analyzing the impacts of these scenarios on wind erosion, and interpreting and suggesting appropriate scenarios for implementation in the area. The Iran Research Institute of Forests and Rangelands (IRIFR.1) model has been selected to create the wind erosion hazard maps for the present condition and for the possible vegetative management scenarios. The Spearman's correlation coefficient indicated a high conformity between the hazard classes of wind erosion map predicted by the IRIFER.1 model and ground evidences. Using the Delphi method weights of wind erosion, gross margin, and establishment costs indices have been determined 0.5, 0.3, and 0.2, respectively. This indicates the high importance of wind erosion issue from experts' consideration. Standardization and trade-off analysis of indices showed that a scenario with a combination of all possible management actions ranked as the best scenario (highest score) despite incurring the largest establishment costs. On the other hand scenarios with single management actions resulted in lowest scores. Finally, the sensitivity analysis of the chosen modeling approach in this study indicated the robustness of the results.

Keywords: Vegetative management scenarios; Wind erosion**;** Trade-off analysis; MCDM; Varamin Plain

1. Introduction

The deserts are naturally fragile ecosystems that are easily disturbed by human interventions. The disturbance in desert ecosystems results in vulnerable conditions which can be readily deteriorated by eroding factors such as water and wind.

Since the pedogenesis process in the arid areas is very slow, soil erosion and sediment transportation in these areas are considered as critical issues (Ekhtesasi and Ahmadi, 1993). Wind force is the dominant factor controlling the soil erosion and sediment transportation rate in arid zones (Refahi, 2001). Therefore, assessment, modeling and prediction of wind erosion in such fragile ecosystems under different management actions and scenarios are vital. Mathematical representation of detachment, transport, and deposition stages of the wind erosion process is used for modeling purposes. During the last four decades many equations and models have been developed and extended (Ekhtesasi and Ahmadi, 1993). Some of well-known wind erosion models

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are WEQ (Wind Erosion Equation), WEPS (Wind Erosion Prediction System), and RWEQ (Revised Wind Erosion Equation). Since these models have been developed on the basis of different environmental conditions and data availability, their application to other areas despite tedious work of calibration do not end necessarily into satisfactory results. Therefore, to estimate the qualitative and quantitative intensity of wind erosion, the IRIFR.1 (the Iranian Research Institute of Forests and Rangelands) model has been developed for arid areas of Iran (Ekhtesasi and Ahmadi, 1993).

Literature review indicates that development and implementation of vegetation-based management actions and scenarios usually decrease the rate of wind erosion in arid areas (Armanino et al, 2000; Rhode et al., 2006). According to the formal report of Tehran Natural Resources Bureau (1999), wind erosion in southern parts of the Varamin Plain is one of the deteriorating factors which should be addressed. One of the main causes of wind erosion and desertification in this area is inadequate management of vegetation cover such as fire wood collection and overgrazing which are observed across whole the study area. Therefore, in this study it is aimed to recognize various possible vegetation management actions across the area and to predict the probable impacts arising from implementing different vegetation-based management scenarios in order to find out best management scenarios alleviating or controlling wind erosion and desertification intensity in the southern parts of the Varamin Plain. In this study to predict the impacts of different vegetation-based management scenarios, the IRIFR.1 model has been adopted and applied. This model uses nine factors to estimate the wind erosion intensity from which two factors of vegetation density and land use and management are directly influenced by vegetation-based management scenarios.

2. Material and methods

2.1. Study area description

Southern part of the Varamin Plain located in zone 49 between 51^{o} 28' – 51^{o} 39' E longitude and 35 ^{o} 02' – 35 ^{o} 29' N latitude has an area of approximately 4320 km^2 (Figure 1). This part of the plain has been affected by desertification processes and wind erosion is the dominant factor across the plain.

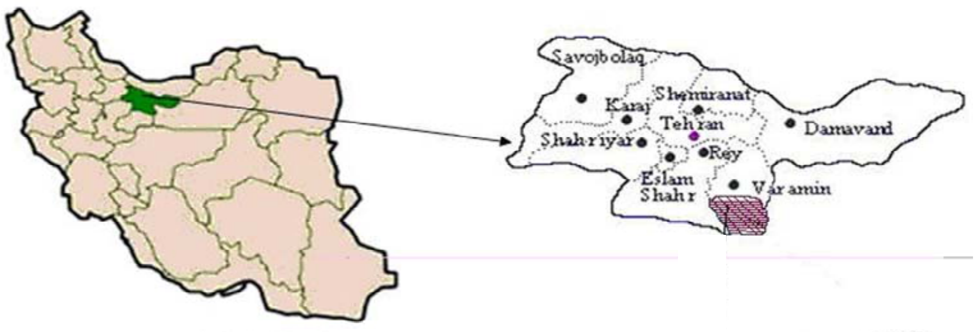

Fig. 1. Location map of the Varamin Plain

2.2. Modeling and analysis method

The IRIFR. 1 model has been applied to assess the wind erosion severity of the area. In the current research, the study area was divided into some homogenous management units by overlaying of soil, vegetation density, and geomorphology map layers. The IRIFR.1 model input map layers include geology, landforms and terrain type, wind speed and direction, soil and land cover, vegetation density, soil erosion features, soil moisture, type and distribution of sand deposits, and land use. These maps were prepared and superimposed using the ArcGIS software to estimate the wind erosion severity over each management unit. The Spearman rank correlation coefficient was calculated to evaluate the accuracy of hazard zonation. The Spearman rank correlation coefficient is usually used when the samples are not normally distributed (Mesdaghi, 2004). It varies between -1 (a perfect negative correlation) and +1 (a perfect positive correlation). To develop management scenarios, all feasible management actions were listed and all of the possible combinations of those actions were considered. In order to determine the feasible management actions, all the planning constraints such as time, costs, labor, efficiency, and regulations were considered. The feasible management actions for the southern parts of the Varamin Plain are enclosure, seeding, seeding accompanied with enclosure, and saltbush plantation. Assuming the present condition as a base case scenario, the number of new scenarios will be $2^n - 1$ in which n is the number of management actions. The base case scenario is regarded as scenario one and the other scenarios are compared with it (Heathcote, 1998). Table 1 presents the scenario development rules.

Table 1. Rules for vegetation-based scenario development for the southern part of the Varamin Plain

Management action	Suitable areas (before implementation of action)	Condition after implementation of actions
Enclosure	Poor & moderate rangelands	Moderate & good rangelands
Seeding	Bare lands	Poor rangelands
Seeding & enclosure	Poor rangelands	Moderate rangelands
Saltbush development	Saline lands	Poor rangelands

For each scenario, the land cover pattern map was synthesized using the query command of the ArcGIS software. By assuming that the other seven input maps of the IRIFR. 1 model are not changing by the management actions, the wind erosion hazard map for each scenario was created. Table 2 presents sixteen vegetation-based scenarios developed for the study area by combining all different management actions.

Table 2. Vegetation-based scenarios developed to manage the wind erosion in the south of the Varamin Plain

Management action	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Enclosure	-	+	-	-	+	-	+	+	-	-	+	-	+	-	+	+
Seeding	-	-	+	-	+	+	-	+	-	-	-	+	-	+	+	+
Seeding and enclosure	-	-	-	+	-	+	+	+	-	+	-	-	+	+	-	+
Saltbush development	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+

The extent of wind erosion hazard classes for each scenario has been compared with the classes of the present condition (base case scenario). The Kappa index of agreement was used for comparison purposes. Several criteria and indices can be used to select the best scenario among various scenarios. Usually a set of criteria which include the public attitude and values are suggested (Heathcote, 1998). However, in this study, the physical and economic criteria were used. Differences between wind erosion hazard maps at the present condition and after implementation of each scenario have been used as the physical index. To this end, the ordinal values of wind erosion hazard classes have been multiplied by their extent and summed up to obtain the value of the physical index. Since the implementation of each scenario will result into changes in the dry mass production, total gross margin and establishment costs were used as two indices of economic criteria. Total gross margin is described as the gross margin minus the variable costs associated with an enterprise/activity (Norman et al., 2002).

The total gross margin generated from a given set of management activities is calculated by Equation 1 (Norman et al., 2002).

$$G = \sum_{j=1}^{m} \left(P_j Y_j - C_j\right) A_j \qquad \text{Equation 1}$$

Where, G is total gross margin; P_j is price of crop j (Iranian Rials per production unit, kg); Y_j is yield of crop j per unit area (ha); C_j running cost of crop j (Iranian Rials per unit area); m is number of crops, and A_j is the area under crop j.

The values of input parameters used in the economic calculations were obtained from the previous rangeland management studies conducted in the study area (Tehran Natural Resources Bureau, 1999).

For vegetation-based scenarios, the establishment costs are identified as labor cost and seed price. The establishment costs of each management scenario have been calculated by Equation 2 (Norman et al., 2002).

$$E = \sum_{i=1}^{n} d_i \left(A_i - \bar{A}_i \right) \qquad \text{Equation 2}$$

Where, E is establishment costs; d_i is the cost of the management activity i; A_i is the area of activity i; $\bar{A}_i$ is the area of activity i for base case scenario; and n is the number of management actions. Therefore, the costs of each management scenario are the sum of all actions' costs.

The linear scale transformation has been used to convert the original index values into standardized index values. There are various methods of linear scale transformation (Sharifi et al., 2004). In this study, the method of maximum standardization has been applied. In this method, to standardize a benefit criteria, the value of each index is divided by the highest value of the index across different scenarios. For instance, to standardize the gross margin index, its value for each scenario is divided by the highest value of the index across different scenarios. For a cost criteria, such as wind erosion (the physical index) and establishment costs (an economic index) Equation 3 (Sharifi et al., 2004) has been used:

$$\text{score}_{\text{standardized}} = 1 - \frac{\text{score}_{\text{i}} - \text{score}_{\text{min}}}{\text{score}_{\text{max}}} \qquad \text{Equation 3}$$

The Delphi method has been used to assign weights to the indices. For this purpose, a panel of six experts in natural resources management have been addressed and requested to weigh the indices on a given scale of 0 to 1. After gathering the responses, they have been collated and returned back to the contributors and requested to revisit the weights in case of inconsistency. This process is repeated until a consensus is reached on the weights assigned to the criteria. Multiple Criteria Decision Making (MCDM) technique has then been applied to evaluate the scenarios. For each scenario, the standardized score of indices have been multiplied by their corresponding weights and summed up to provide a criterion for evaluation purpose. The scenarios with higher total sum of weighted scores have been identified as the best ones. For visual comparison of the index values associated with each scenario, segment diagram presentation was utilized. A sensitivity analysis has been carried out to determine the dependency of results to the weights of the indices (Knack, 1996).

3. Results

3.1. Model analysis

The input parameters of the IRIFR. 1 model were estimated and summed up to predict the wind erosion severity of management units across the management scenarios and their respective wind erosion hazard maps were then synthesized. For instance, Figure 2 and Table 3 show the wind erosion hazard map and the extent of wind erosion hazard classes of the study area for the present condition, respectively.

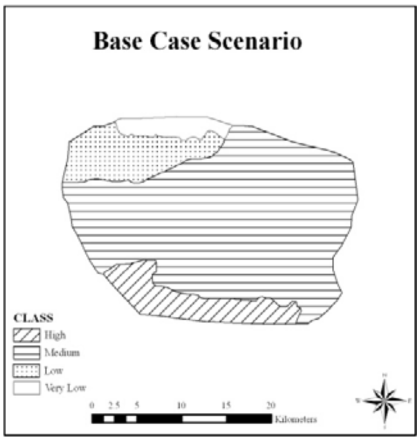

Fig. 2. Wind erosion hazard map of the southern parts of the Varamin Plain for the present condition

Also the wind erosion hazard maps corresponding to scenarios containing single actions have been displayed in Figure 3. According to the IRIFER model, the differences observed in the wind erosion hazard maps of the management scenarios are due to the changes in two input parameters of vegetation density and land use type.

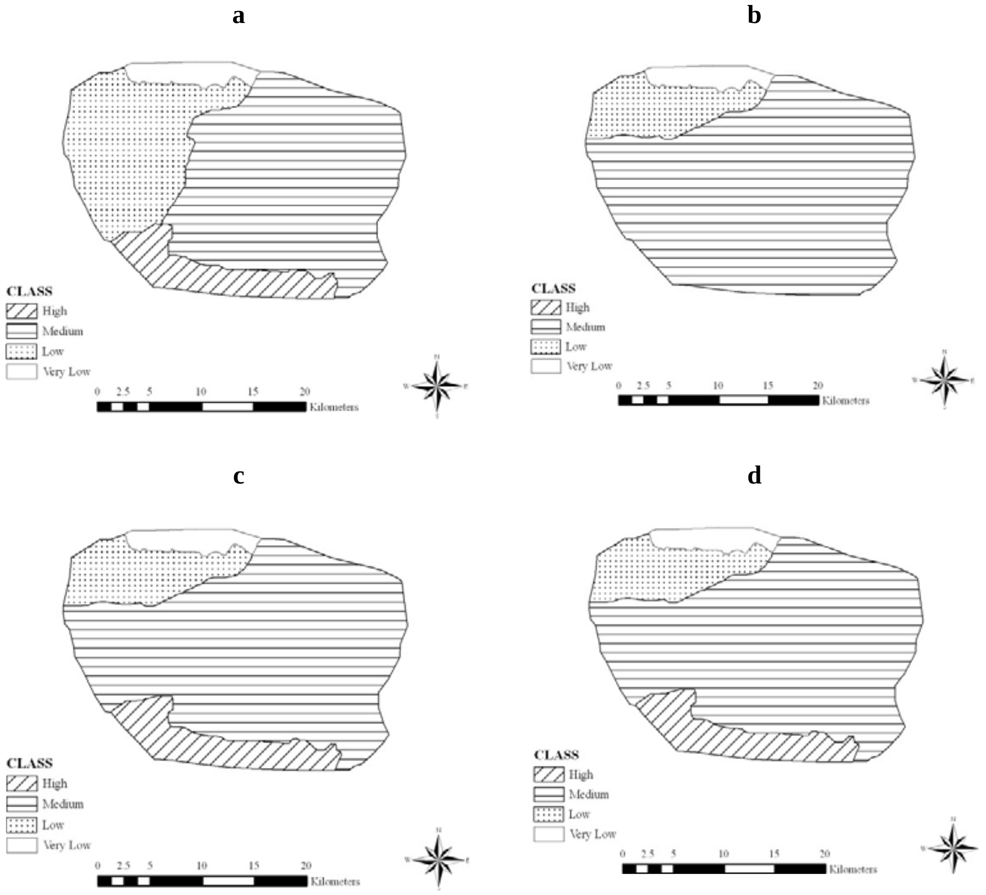

Fig. 3. Wind erosion hazard maps corresponding to the single action management scenarios.
a: enclosure, b: seeding, c: seeding and enclosure, and d: saltbush development

The wind erosion hazard map of the present condition was compared with those of the other management scenarios pairwise. Table 3 presents the results of the comparisons applying the Kappa-index of agreement. As shown in the table, the degree of agreement varies from 0.01 to 0.4. The low degree of agreement indicates the significant impact of the management scenarios.

Table 3. The Kappa-index of agreement of wind erosion hazard for scenario1 against the other scenarios

Scenario	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Kappa index	0.12	0.01	0.17	0.14	0.03	0.1	0.34	0.41	0.29	0.19	0.21	0.03	0.24	0.02	0.01

3.2. Indices analysis

The following assumptions were made to quantify the economic indices. The price of unit of dry mass production is 900 IRI Rls. The enclosure, seeding, saltbush development, and combination of seeding and enclosure will increase the dry mass production by 100, 80, 90, and 140 kg.ha^{-1}, respectively. The implementation of each scenario incurs some establishment costs which are about 80,000 and 117000 IRI Rls per hectare for seeding and saltbush development actions, respectively. There is no establishment cost for enclosure. In addition, for some actions there are some running costs (variable costs) which should be figured out. They include preparation, re-plantation, enclosure, maintenance, and harvesting costs. For eight-year decision horizon, the total costs of seeding, saltbush development, and seeding and enclosure have been estimated 160,000, 117,000, and 182,000 IRI Rls per unit area, respectively. Figure 4 illustrates the change in total gross margin for each scenario and Figure 5 shows the establishment costs corresponding to each scenario.

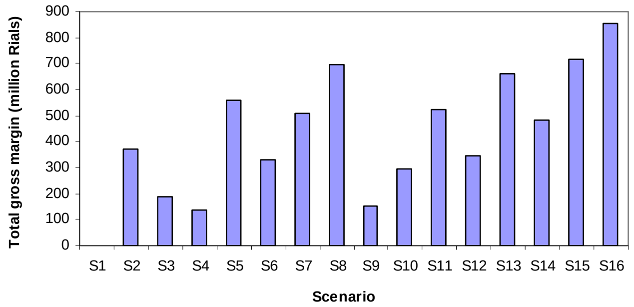

Fig. 4. The change in total gross margin across 16 management scenarios

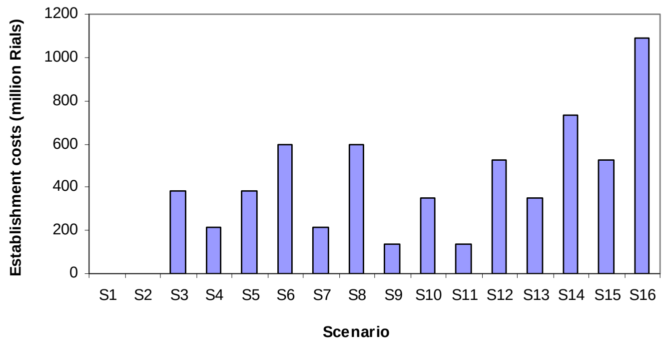

Fig. 5. The establishment costs across 16 management scenarios

To quantify the physical index, the wind erosion hazard maps corresponding to various scenarios were used. For each scenario, the rank of each wind erosion hazard class has been multiplied by its extent and summed up to obtain the quantitative value of the physical index. Figure 6 displays the quantitative value of the physical index for various management scenarios.

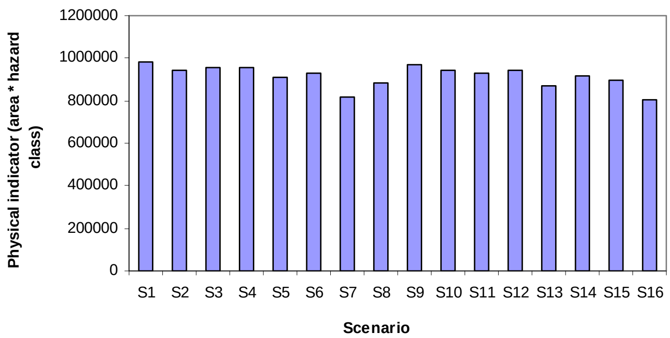

Fig. 6. The physical index across the management scenarios

3.3. Trade off analysis

The Delphi approach has been applied to assign the weights to the indices. Based on this approach the weights of wind erosion (physical index), gross margin, and establishment costs (economic indices) have been determined to be as 0.5, 0.3, and 0.2, respectively. After standardization of the indices, their values were multiplied by their weights and summed up to obtain the final score for each scenario. The final scores were sorted in descending order and ranked from 1 to 16. Table 4 shows the final scores of the scenarios. The scenarios S16, S7, S8, and S13 ranked from 1 to 4, respectively.

Table 4. Final scores of management scenarios in the Southern parts of the Varamin Plain

Scenario	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Final score	0.3	0.4	0.45	0.35	0.43	***0.82****	***0.8***	0.53	0.50	0.55	0.59	***0.79***	0.63	0.68	***0.96***

*: Italic bold scores indicate the scenarios with better performance

A suitable visual technique assists in representing and interpreting multivariate data sets. Thus, segment diagram presentation was utilised to represent the outcome variables corresponding to each management scenario (Figure 7). In segment diagrams the values of variables are scaled independently so that the maximum value (or 'best') in each variable is 1 and the minimum (or 'worst') is 0. Segment diagrams facilitate comparison between cases. To facilitate comparison among the management scenarios in segment diagrams, for those variables with adverse impacts, their inverted values are represented in the diagrams. This is the case for 'establishment costs' and 'physical index'. That is, an 'increase' in all variables corresponds to a good outcome. Hence, the radii of the diagrams show the level of achievement of management objectives considering all impact indices.

Table 5. Weights of the indices regarding the different perspectives for sensitivity analysis

Perspective	Wind erosion	Gross margin	Establishment costs
Physical	60	20	20
Economic	20	40	40
Equivalent	33	33	33

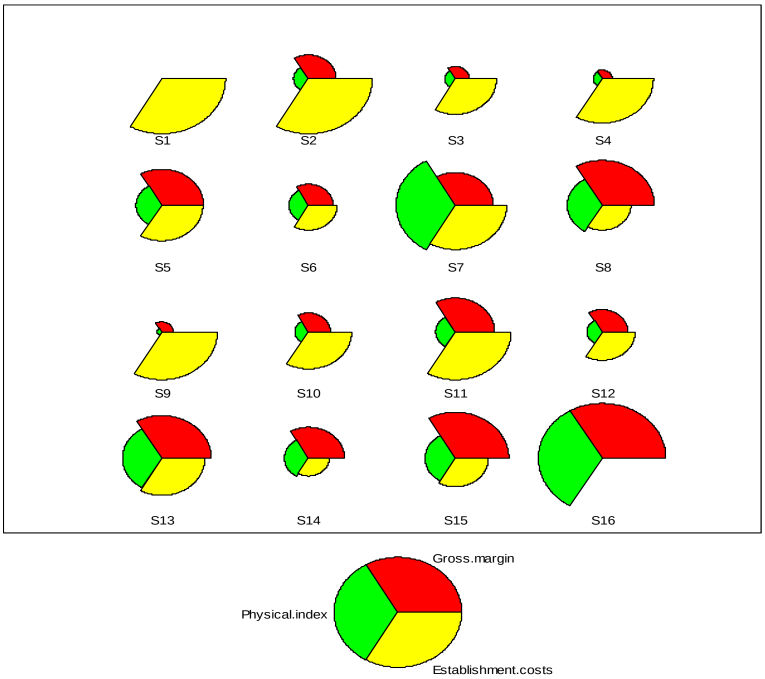

Fig. 7. Values of impact indices for the 16 management scenarios in the southern parts of the Varamin Plain

Table 6. Final scores of management scenarios considering the different perspective for sensitivity analysis

Perspective	Scenario															
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Physical	0.30	0.50	0.51	0.55	0.59	0.60	*0.82* *	*0.78*	0.66	0.70	0.73	0.73	*0.80*	0.68	0.73	*0.97*
Economic	0.49	0.71	0.67	0.69	0.70	0.70	*0.85*	*0.83*	0.71	0.75	0.76	0.76	*0.83*	0.77	0.71	*0.93*
Equivalent	0.42	0.64	0.61	0.64	0.66	0.66	*0.83*	*0.81*	0.69	0.72	0.74	0.74	*0.84*	0.78	0.71	*0.93*

*: Italic bold scores indicate the scenarios with better performance

Trade-off analysis indicates that the scenarios S16, S8, S7, and S13 are best scenarios to control wind erosion hazard in the southern parts of the Varamin Plain. To investigate the robustness of the results a sensitivity analysis has been carried out. To this end, we used three different perspectives, in each a specific index was emphasized on. Table 5 summarizes the weights corresponding to these perspectives and table 6 presents the results obtained. It shows that the results of different perspectives do not significantly differ from the results of the Delphi approach (Table 6). As can be seen, the best group of scenarios is identical, but the rank of these scenarios changes slightly from one perspective to another. This indicates that the results are relatively insensitive to the weights assigned to the indices.

4. Discussion

Based on the IRIFR.1 model, land use type and vegetation density are the two important parameters controlling wind erosion hazard. Therefore, choosing and implementing appropriate land use types and management practices are necessary to control wind erosion in a region. Using a scenario-based approach is a straightforward and efficient way to understand different outcomes of implementing management scenarios. Since each management scenario may have some positive or negative physical and economic impacts, a MCDM approach has been applied to trade off various impacts and choose best scenario/s.

The Spearman's correlation coefficient indicated a high conformity between wind erosion hazard classes predicted by the IRIFER.1 model and ground evidences. This indicates the appropriate performance of the IRIFR.1 model to assess wind erosion hazard classes in the southern parts of the Varamin Plain. The minimum and maximum degrees of agreement correspond to the Scenario16 and Scenario 9, respectively. This is mostly due to the extent of the areas allocated to the management actions. For instance, in Scenario16 all the management actions were implemented over the suitabe areas across the study area while in Scenario 9 only a limited proportion of the study area, suitable for the action, was allocated to saltbush development.

To develop the scenarios, the technical limitations in relation to the management actions have been considered. It was also assumed that there are no serious ecological and social limitations for implementation of the management actions. In other words, all of the scenarios were considered to be feasible.

Considering the physical index, the best scenario is the one that corresponds to an erosion map with a minimum proportion of high wind erosion hazard classes. While considering the economic indices, the scenarios which result in minimum establishment costs and maximum total gross margin are identified as best scenarios. Scenario S7, S16, S13, S8, S15, S5, and S14 are appropriate scenarios when only the physical index is considered. Considering the total gross margin index, scenarios S16, S15, S8, S13, and S5 are among best group of scenarios. While regarding the establishment costs, the best group of scenarios is identified as S1, S2, S9, S11, S4, and S7. However, when the physical and economic indices are collectively considered the order of best scenarios differs markedly. To do this, a MCDM approach has been used. Based on this approach, the scenarios S16, S7, S8, and S13 have been ranked as best group of scenarios to control wind erosion in the study area.

To evaluate the different management scenarios, they have been compared with the present condition. This is similar to the methodology implemented by Armanino et al. (2000), and Sadoddin (2006) and has been suggested by Heathcot.

The sensitivity analysis revealed that the results of the MCDM analysis are not significantly affected by the various weights assigned for different perspectives. The sensitivity analysis indicated that four scenarios S16, S13, S8, and S7 were among best scenarios regardless of the weighting perspectives. These four scenarios are identical with the scenarios chosen by the Delphi approach as best scenarios. This indicates the robustness of the results obtained in this study.

Although for some scenarios such as S16, S13, S7, and S8 the physical index shows a significant improvement, the implementation of some management scenarios has minor impact on soil erosion classes. Hence, for several management scenarios soil erosion hazard classes are quite similar to the hazard classes identified for the current condition (S1). Large increments of the scores concerning the soil erosion hazard classes, which restrict the number of classes specified in the IRIFR. 1 model, are responsible for the shortcoming of the model to detect the impacts of some management scenarios. This suggests that some revisions in the IRIFR model need to be made in order to get the model more responsive to the changes in management and land use factor as well as in vegetation density factor. One solution might be an increase in the number of hazard classes in the model itself.

Also it should be noted that to provide a more comprehensive and informative analysis it is required to incorporate other components of the decision making model used in this study with taking into account the social and ecological outcomes arising from implementing management scenarios along with the physical and economic outcomes. This integrated approach is a useful way to inform policy makers and watershed managers about the possible outcomes of their decisions on wind erosion and therefore can be a basis for development of soil erosion management programs in the study area.

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