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Application of MCDM for biologically based management scenario analysis in integrated catchment assessment and management

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ABSTRACT

The development and implementation of practical natural resources and catchment management policies require a comprehensive knowledge of the system processes (biological, physical, and socioeconomic), their complicated interactions, and how they react to different changes. The current research assessed the ecological, physical, and socioeconomic consequences of biologically based management scenarios targeting runoff and soil erosion problems in the Darenari catchment. The Darenari catchment with an approximate area of 554 ha is located in Fars Province, Iran. Three biological activities and 8 management scenarios were considered. Ecological consequences were studied using the weighted land cover area index. Physical effects were investigated applying the Soil Conservation Service hydrologic model. Economic and social effects were assessed applying the cost/benefit analysis as well as examining the outcomes of a social survey. The best scenarios were identified applying a multiple-criteria decision-making technique. A fuzzy analytic hierarchy process approach was applied to weight the criteria. The results indicated that multiple-criteria decision-making is a useful technique for demonstrating the catchment system as a whole, to integrate output from models and expert judgments.

Keywords: Multiple criteria; Fuzzy AHP; Ecological; Physical; Socioeconomic; Integrated watershed management

1. Introduction

Increasing population in recent decades has begun to stretch demands for food and other goods that in turn causes soil and water degradation. This presents a challenge in many parts of the world and in developing countries in particular. There are also socioeconomic welfare issues that arise from unsuitable use of soil and water resources.

The difficulty of environmental and natural resource assessment and management is reflected in the comprehensive management-related studies [1–10]. Catchments are living ecosystems, including interconnected webs of water, biota, land, and human beings [11]. Stream flows integrate by catchments as natural integrators and, as a consequence, of human activities [12].

Managers apply catchments as planning and management units that help them to have a comprehensive view of the interlinked elements of an area and the catchment [11]. Integrated catchment management attempts to solve catchment problems based on sustainable development [13]. Integrated catchment management is globally acknowledged as a suitable method for the management and planning of water, land, and related resources, and ultimately achieves ecosystem sustainability as consequence. Applying an integrated catchment management method helps to take all major components and events impacting water resources into analysis [14]. Considering the condition and nature of catchments as a particular class of management systems, integrated catchment management supplies a structure for integrating knowledge and aspects of the

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social, economic, and environmental sciences into assessment, planning, and management [15]. All suggested plans in the catchment management area must be defendable, while simultaneously analyzing reaction and feedback mechanisms among various factors of the system, accounting for biophysical, social, and economic regards, and remove all conflicts involving the particular needs of resource-user groups in the catchment system [16]. The analysis of issues, driving components, different aspects such as biophysical and socioeconomic, catchment stakeholders, data, and models of various scales are factors in integrated catchment assessment, planning, and management [17]. Assessment, planning, and management will improve through an exact understanding and trade-off analysis of consequences from the implementation of various management activities on different spatial and temporal scales.

The management of catchment sources is inherently a complex undertaking, not only because of its wide scope but also because of the broad range of characteristics that bear on it. Operationally, catchment source modeling and management must deal with characteristics that are hard to explain and components that may involve both qualitative and quantitative elements. In terms of scope, management may include geographic regions where boundaries are simply not recognizable or socioeconomic areas that influence different interests of stakeholders, each of whom has his/her own requests and socioeconomic requirements [18]. In view of these difficulties, this research suggests techniques based on fuzzy logic for undertaking such a complicated management process. Fuzzy techniques are deliberately developed for complex issues such as catchment management.

The concept of fuzzy set theory, initially introduced by Zadeh [19], is originally based on fuzzy analytic hierarchy process (AHP) methodology. The fuzzy AHP method can be considered an improved analytical technique developed from the conventional AHP. In spite of the easiness of AHP in handling quantitative and qualitative criteria of multi-criteria analysis issues based on decision maker's evaluations, fuzziness and uncertainty in various decision-making issues may contribute to inexact estimates of decision makers in the traditional AHP process [20].

The analysis of hierarchical structures in a fuzzy environment was originally suggested by Buckley [21], who studied the state of decision makers concerned with pairwise comparisons while applying fuzzy ratios instead of crisp values. Various fuzzy AHP techniques have been suggested [21–25]. The framework and a detailed description of the fuzzy AHP and its utilizations in different cases can be found in other studies [18,26–36].

Many authors have studied the application of different methods such as multiple-criteria decision-making (MCDM) in catchment modeling and management [37–50]. Eder et al. [51] reports on use of MCDM to choose location and design options for hydroelectric power plants on the River Danube in Austria. Al-Rashdan et al. [52] reports application of MCDM to prioritize in projects to improve the environmental quality of the Jordan. Flug et al. [53] reports on use of MCDM to choose water flow options for Glen Canyon Dam in Colorado to provide recreation, biodiversity, fishing, and cultural activities. Qureshi and Harison [54] reports application of AHP to determine how five stakeholder groups ranked four riparian vegetation options for the Johnstone River catchment in North Queensland, Australia. Joubert et al. [55] reports on application of multiple-criteria decision analysis (MCDA) in making selections for water supply augmentation and water demand management policy for the city of Cape Town in South Africa. Kepner et al. [56] reports on analysis of future scenarios in the form of land-use/land-cover grids relative to their effects on surface-water conditions. Abrishamchi et al. [57] reports application of MCDM to select the best management scenario of urban water supply for the city of Zahedan in Iran. Liu et al. [58] proposes an optimization technique based on scenario analysis for handling catchment management under uncertainty. The method applied to the case of the Lake Qionghai watershed in southwestern China integrates system analysis, forecast methods, and scenario analysis, as well as the contributions of stakeholders and experts, into a comprehensive framework. Macary et al. [59] reports on combining the ELECTRE III as a MCDA method to geographical information system (GIS), in order to identify areas at risk from emission and transfer of suspended solids toward streams of the Oir catchment in Normandy, France. Sadoddin et al. [14] assessed the physical and socioeconomic consequences of vegetation-based management scenarios targeting flooding and soil erosion problems for integrated catchment management in Iran. The best activities and scenarios were recognized when applying a MCDM technique. Results indicated that MCDM is useful in presenting the natural and catchment system as a whole and incorporating output from models and expert judgments to analyze the trade-offs among consequences necessary to decision-making [33–36,60–63]. Ghanbarpour and Hipel [64] reports application of a multi-criteria framework applied to land prioritization for achieving multi-stakeholder and sustainable planning at different spatial scales comprising sub-watershed and land unit levels in the Kan watershed, Iran. Keshtkar et al. [13] applied the Bayesian decision networks (BDNs) to analyze the socioeconomic, ecological, and biophysical consequences of biological scenario activities for integrated catchment management in Iran and determined the best management scenarios. They concluded that a BDN is a valuable tool that helps probabilistic assessment and risk analysis for integrated catchment modeling and management in uncertainty. Kanwar et al. [65] reports application of the relative risk model to prioritize management of sources of stress to habitats of the Kaipara Harbour catchment in New Zealand. The results of that research showed that policy makers, managers, conservation groups, and municipalities were able to inform future management efforts in the catchment. The objectives of this research were to develop and present an approach to be applied for integrated catchment management and to determine the best management activity and scenario.

2. Materials and methods

2.1. Study area

The Darenari catchment, located in the south of Iran, 30 km from Shiraz (the center of Fars Province) and west of Maharlou salt lake, has an area of about 554 ha (Fig. 1). Its geographic position lies between 52°45′–52°48′ E longitude and 29°21′–29°22′ N latitude, and its elevation ranges from 1,532 to 2,620 m mean sea level.

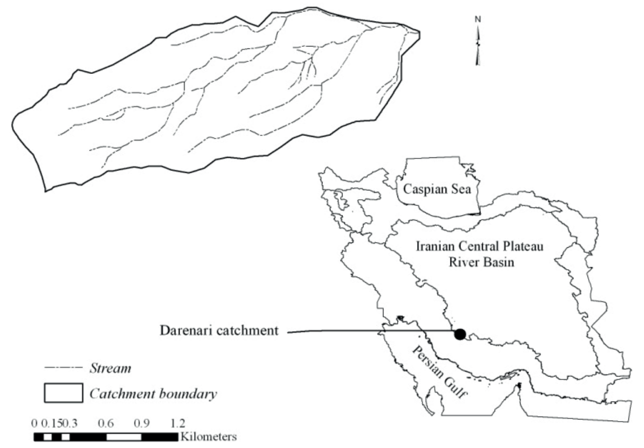

Fig. 1. Geographical location of the study area in Iranian Central Plateau river basin (right) and map of the Darenari catchment (left).

The dominant economic activities in study area included fruit production (almond, pomegranate, pistachio, and fig), irrigated agriculture (wheat, barley, and kitchen garden), and rain-fed farming. Some families kept animals such as cattle, sheep, and goats; these were kept in the traditional way. Nomadic tribes occupied the area during some seasons. Annual precipitation averages 493 mm and mainly falls during the winter, and average daily temperature is about 14.3°C. Based on de Martonne classifications, the climate of the study region is mild Mediterranean [66].

Studies have shown that runoff, soil erosion, and sedimentation in the area were mainly influenced by topographic conditions such as high slope, rain intensity and pattern, geological formation, low permeability, as well as rangeland condition and vegetation cover, and factors that can lead to runoff and destructive floods and that increase rates of soil erosion and sediment transport [9]. Rangeland is the dominant land cover type in the catchment. However, similar to most of the arid and semi-arid regions of Iran, land use change from rangelands to agriculture in some parts of the study region and also overgrazing have caused on-site soil degradation and off-site sedimentation downstream [9]. Because of the catchment's susceptibility to high flooding, the implementation of flood mitigation activities is required. Moreover, because of the susceptible geological formations, water erosion such as gully erosion, drought, and change in land use from rangeland to agriculture have caused on-site soil degradation and off-site sedimentation downstream to increase [66].

To prevent a reduction in catchment resources such as water, soil, and vegetation, the scenario-based approach was applied in this research to predict the consequences of various management activities within an integrated catchment management framework.

2.2. Methodology

2.2.1. Approach to catchment management applying scenario analysis

Compared with mathematical optimization models, scenario-based methods are able to increase catchment stakeholders' understanding of the catchment system [67]. Such approaches make it possible for users to select various management scenarios and assess their probable positive and/or negative results. The current research applied a scenario-based method with the intention of supporting managers rather than making decisions for them [14]. This method increases our knowledge about catchment system and its function, and it aids in determining the best management activities.

Table 1
Biologically based management scenarios for the Darenari catchment

Scenario	1	2	3	4	5	6	7	8
Activity								
Seeding	–	+	–	–	+	+	–	+
Sowing	–	–	+	–	+	–	+	+
Grazing management	–	–	–	+	–	+	+	+

Note: + sign shows the presence, and – sign shows the absence

2.2.2. Developing biologically based management scenarios

Firstly, sources of surface runoff and sediment issues over the Darenari catchment were determined in land management units. These units were determined according to slope, geological formation, land use, vegetation cover, soil condition, and erosion. The next step was to list all possible ways to alleviate effects of these conditions for each land management unit. Implementation of every management action was investigated according to the situation of each unit in terms of including technical (as mentioned above, e.g., slope, geology, etc.), socioeconomic condition, and time possibilities. Retaining current conditions can sometimes allow a catchment to improve itself through natural evolution, especially once there is no large-scale catchment disturbance [1]. Moreover, it can be applied as a base case scenario to assess other scenarios.

After simultaneous management activities in the research area were ascertained, all feasible management actions were determined considering the limitations existing in the catchment. The three biological activities of sowing, seeding, and grazing management were identified for the Darenari catchment. These three activities were combined, which led to 8 (2^n) various management scenarios (Table 1).

Management scenarios must be exclusive. In fact, the acceptation of 1 scenario means the refusal of all others.

Input map layers consisted of geology, slope, land use, type and density of vegetation cover, and erosion intensity. These were provided and determined as a land management unit with a minimum size of 10 ha. This size of management unit was selected to establish suitable habitat size and in consideration of a realistic, on-ground management intervention [68]. Then, these layers were added to the ArcGIS environment to determine the spatial distribution of different management actions according to the scenario development rules indicated in Table 2. Suitable areas for each biologically based action were allocated for each scenario.

Table 2
Suitable area for biological management actions of the Darenari catchment

Biological activity	Suitable area
Seeding	Rangelands with semi-deep to deep and moderate soil textures, moderate vegetation density, and severe erosion, slope less than 20%
Sowing	Rangelands with semi-deep to deep and moderate soil textures, moderate vegetation density, and severe erosion, slope more than 20%–25%
Grazing management	Rangelands with light to semi-heavy soil textures, moderate vegetation density, and low soil erosion, various slopes

2.2.3. Analysis of integrated management of the Darenari catchment

Criteria were identified for assessment of the scenarios. The terms of reference of the research team were determined as the overall aim: 'integrated catchment management' that was obtained through the sub-objectives of catchment improvement, sustainable and suitable land and water use, decreasing runoff and soil erosion, and the promotion of economic growth. Criteria for analysis of scenarios were based through further refinement of these aims, while others were based either on data arising from the research and previous studies or on the opinion of a relevant specialist on the research team based on their previous experience and work in the area. The formed criteria were based on the problems by which the scenarios were analyzed by the research team, so the scenarios were analyzed according to four criteria.

2.2.3.1. Modeling of consequences of biologically based activities

2.2.3.1.1. Modeling of physical consequences of biologically based activities Modeling was necessary to measure ungauged catchment runoff; therefore, direct measurement of flow of the stream was applied to predict results and consequences of biological management actions implementation. There are several methods available to evaluate ungauged catchment runoff. Among these methods, the Soil Conservation Service (SCS) curve number (CN) method is a simple but well-established, widely used and efficient method; it features easy to obtain and well-documented environmental inputs and considers many factors that affect generation of runoff such as the area's hydrologic soil group, land use, treatment, and hydrologic condition [69–75]. As a catchment loss model, it has no rival in the area of design models [76]. Thus, the effects of change in vegetation cover on hydrological characteristics were simulated using an SCS–CN model. This model may relate the catchment attributes to the flow parameters. Antecedent soil moisture condition, hydrologic soil group, and land use type were used to compute the CN. The model calculated the precipitation excess depth, peak discharge, and time to peak over the catchment. Peak discharge was computed using Eqs. (1) and (2) [14,77]:

$$Q_p = \frac{2.083AR}{t_p} \quad (1)$$

$$t_p = \frac{D}{2} + t_1 \quad (2)$$

where Q_p is peak discharge in m^3/s; A is catchment area in ha; R is rainfall excess in mm; t_p is time to peak in h; D is duration of rainfall excess in h; and t_l is watershed lag time in h. The 100-year discharge volume for the study area was computed by multiplying the 100-year peak discharge by the related time to peak.

2.2.3.1.2. Modeling of economic consequences of biologically based management activities The consequences of changes in vegetation cover affecting economic conditions were calculated and predicted using gross margin and variable indices. Total gross margin of each scenario was computed using Eq. (3):

$$Y_i = \sum_{i-1}^{n} \left[p_i - c_i \right] A_i \quad (3)$$

where Y_i is yield of harvest i (unit of production per unit of area); P is the price of harvest (Iranian rials per unit of production); C is variable costs of harvest i (Iranian rials per unit area); A is the area allocated to harvest i (unit area); and n is the number of actions. To evaluate the economic results of biologically based management actions, a decision horizon of 8 years was selected based on the time needed for planted vegetation to mature to economical harvesting phase. Watershed Management, Rangeland and Forest Organization (WMRFO) was determined as the source of harvest price and cost data.

2.2.3.1.3. Modeling of social consequences of biologically based management activities Aim and range of management questions determined the number of stakeholders who should be consulted [14]. An understanding of stakeholders' time, costs, practicality, and diversity and dynamism is required [78]. Cochran's [79] sample size method was applied to determine sample size for social evaluations. In the initial evaluation, 30 stakeholders (as a sample of the catchment community) were consulted in a social evaluation to assess the level of acceptance of management activities among the community. Social survey participants were questioned about their intents to implement the biologic scenarios in the 4 years ahead. The outcomes of the initial survey revealed a good constancy among the viewpoints of the stakeholders. Thus, it was supposed that the sample size of 30 stakeholders was acceptable. Results of the social evaluation were applied to analyze the probable social outcomes of efforts to perform the management activities in the catchment. Binomial probability distribution was applied to this end. The trials were independent from the probability of compliance (p); the same was found for y trial in the class of the binomial probability analysis [40,80]. Probability was computed for success of y in n trials by Eq. (4):

$$P_{r(yi)} = \frac{n!}{Yi(n-i)!} pi^{yi} \times qi^{n-yi} (y_i = 0,1,2,\ldots,n) \quad (4)$$

where n is the number of trials (30 participants); P_i is the probability of compliance (positive answer) of the scenario i in each trial; q_i is probability of non-compliance (negative answer) of the scenario i in each trial; y_i is the number of compliance of the scenario i in n trial; $P(y_i)$ is the probability of y_i acceptance in n trials; and i is scenario number (1, 2, …, 8). Four levels of acceptance, including no acceptance, low acceptance, moderate acceptance, and high acceptance, were applied to determine the community acceptance toward vegetation-based scenarios. The following assumptions were applied to identify level of community acceptance. If 3 out of 30, 4–9, 10–21 and more than 22 trials were positive, then it implied that the management scenario was rejected (no acceptance), as low, moderate, and high acceptance levels, respectively. Table 3 shows probability of compliance of the 8 scenarios. It should be mentioned that p_i is the determined probability of acceptance when financial support such as subsidy, interest-free loan, and other incentives are provided for reclamation of vegetation condition in the catchment.

2.2.3.1.4. Modeling of ecological consequences of biologically based management activities The weighted land cover area index (WLCAI) is a sum total measure of natural areas against improved landscapes in the catchment. It was chosen because calculating the area of various lands covers and considering a related weight help evaluate the rate of naturalness in the catchment. In a biodiversity conservation context, calculating the rate of 'naturalness' supplies valuable information to contribute to wider conservation value evaluations [81]. Furthermore, a comparison between various land cover types is another critical process necessary for evaluating the quality of native vegetation [41,82]. WLCAI was calculated using following equation:

$$\mathrm{WLCAI} = \sum_{m=1}^{7} \alpha_m \sum_{k=1}^{nm} p_{k,m} \quad (5)$$

where m is the land cover type (see Table 4), nm the number of patches of land cover m type, $P_{k,m}$ the size of each of the patches (k = 1, ..., nm), and α_m the weight value for each land cover type m (see Table 4). An increase in WLCAI implies reclaiming the catchment conditions in terms of rate of naturalness.

2.2.3.2. Modeling integrated catchment and management using a fuzzy AHP approach Compared with other methods on fuzzy AHP, Chang's extent analysis is comparatively simpler.

Table 3
Stakeholder acceptance probability of the management scenarios

Scenario	*Pi*
1	0.05
2	0.33
3	0.55
4	0.13
5	0.85
6	0.33
7	0.55
8	0.95

Table 4
Weight values for various land covers [14]

Land cover type	*m*	*αm*
Tree	1	1
Riparian	2	1
Seeding	3	0.1
Sowing	4	0.3
Native pasture	5	0.6
Improved pasture	6	0.3
Saltbush	7	0.75

In the current research, Chang's extent analysis approach was applied for assessing and prioritizing biological management scenarios in the Darenari catchment in Iran.

The first step in this method was to apply triangular fuzzy numbers for pairwise comparison by means of the fuzzy AHP (FAHP) scale, and the next step was to apply the extent analysis method to get priority weights by applying synthetic extent values. The theoretical fundamentals of Chang's extent analysis on FAHP were explained in four stages.

The two sets, $X = \{x_1, x_2, x_3, ..., x_n\}$ as an object set, and $G = \{u_1, u_2, u_3, ..., u_m\}$ as a goal set, can be defined in the initial stage. According to the principles of Chang's extent analysis, each object is considered correspondingly, and extent analysis for each of the goal, g_i, is executed. It means that it is possible to obtain values of m extent analyses demonstrated as $M^1_{(g_i)}, M^2_{(g_i)}, \ldots, M^m_{(g_i)}, i = 1, 2, \ldots, n,$ where $M^j_{(g_i)} (j = 1, 2, \ldots, m)$ are triangular fuzzy numbers. After identification of initial assumptions, Chang's extent analyses can be calculated in four main stages as follow:

Stage 1: The value of fuzzy synthetic extent with respect to the ith object is represented as, $S_i = \sum_{j=1}^{m} M^j_{g_i} \otimes [\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{g_i}]^{-1}$, and fuzzy addition operation of m extent analysis values can be performed for particular matrix such that $\sum_{j=1}^{m} M^j_{g_i} = (\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j)$ to calculate $\sum_{(j=1)}^{m} M^j_{(g_i)}$. Next, the fuzzy addition operation of $M^j_{g_i} (j = 1, 2, \ldots, m)$ values such that $\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{g_i} = (\sum_{i=1}^{n} l_i \sum_{i=1}^{n} m_i \sum_{i=1}^{n} u_i)$ are performed to calculate $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{gi}\right]^{-1}$. Finally, the inverse of the specified vector can be indicated as follows:

$$[\sum_{i=1}^{n} \sum_{i=1}^{m} M^j_{g_i}]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (6)$$

Stage 2: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1$ is defined as $V(M_2 \geq M_1) = \min(\lambda_{M_1}(x), (\lambda_{M_2}(y)_{y \geq x}$, and it can be indicated as follows:

$$V\left(M_2 \geq M_1\right) = hgt\left(M_1 \cap M_2\right) = \lambda_{M_2}(d)$$

$$= \begin{cases} 1, & \text{if } m_2 \geq m_1, \\ 0, & \text{if } l_1 - \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \quad (7)$$

where d is the ordinate of the highest intersection point between μ_{M_1} and μ_{M_2}. In order to compare, we required both values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

Stage 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i ($i = 1, 2, ..., k$) can be explained by:
$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1)$, and $\times (M \geq M_1) \ldots$ and $(M \geq M_k)]$ min $V(M \geq M_i)$,
$i = 1, 2, 3, \ldots, k$
Assume that $d'(A_i) = \min V(S_i \geq S_k)$. For $k = 1, 2, \ldots, n, k \neq i$. Then the weight vector is given by $W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T$, where A_i ($i = 1, 2, \ldots, n$) are n elements.

Stage 4: Via normalization, the normalized weight vectors are $W = (d(A_1), d(A_2), \ldots, d(A_n))^T$, where W is a non-fuzzy number that gives priority weights of an attribute or an alternative over another.

3. Results and discussion

3.1. Consequence analysis of biological management activities

Research criteria were determined according to importance and priority. The relative weight of each selected criteria was extracted from the fuzzy AHP technique based on a pairwise evaluation of the options. Different weights were given to the criteria based on four various aspects that might be chosen by experts who are involved and have enough knowledge about the research area problems or by some of the stakeholders who are part of the village councils of Mahmoudabad and Maharlou villages in the Darenari catchment. The normalized weights of the criteria and comparative weighting of biological activities into criteria are shown in Tables 5 and 6.

Consistency of the matrices were checked, and the priority of the factors was compared by computing eigenvalues and eigenvectors, which were less than 0.1 and about 0.04, respectively, based on the results of matrix consistency analyses. Then, the normalized weights of indicators were multiplied by their weights and summed up to identify the best scenario(s). The results of prioritization of biological activities and scenarios in various weighing aspects are shown in Tables 7 and 8.

According to the results shown in Table 1, social criteria are the most important compared with other criteria. Social criteria are strongly dependent on the stakeholder contribution rate in implementing the suggested scenarios and biological activities, because stakeholders may participate in rangeland improvement projects as unskilled workers during the seasons they are not busy with agriculture and animal husbandry activities. In fact, they have more free time and prefer to get revenue by working in these projects. Since the council members of the villages were educated and had enough knowledge of the positive outcomes of biological

Table 5
Normalized and ranked weights of the criteria of Darenari catchment management

Criteria	Weight	Rank
Ecological	0.21	2
Social	0.223	1
Physical	0.198	3
Benefit	0.191	4
Cost	0.178	5

Table 8
Prioritization of management scenarios of Darenari catchment management

Number	Scenarios	Weighs based on FAHP	Priority
1	Base case	0	8
2	Seeding	0.22	7
3	Sowing	0.43	5
4	Grazing management	0.33	6
5	Seeding and sowing	0.66	3
6	Seeding and grazing management	0.56	4
7	Sowing and grazing management	0.78	2
8	Seeding, sowing, and grazing management	1	1

Table 6
Comparative weighting of biological activities into criteria in Darenari catchment management

Criteria		Ecological	Social	Physical	Benefit	Cost
Activities	Sowing	0.44	0.58	0.37	0.48	0.3
	Seeding	0.17	0.12	0.26	0.02	0.58
	Management	0.39	0.3	0.37	0.5	0.12

Table 7
Prioritization of biological activities of Darenari catchment management

Criteria		Ecological	Social	Physical	Benefit	Cost	Final weight	Rank
Activities	Sowing	0.09	0.13	0.07	0.09	0.05	0.45	1
	Seeding	0.04	0.03	0.05	0.01	0.1	0.22	3
	Management	0.08	0.07	0.07	0.09	0.02	0.33	2

activities, they were interested in reclaiming degraded rangeland for soil and water resource conservation. Ecological and physical criteria contributed almost 21% and 20%, respectively. These results refer to the priority of social issues, even compared with economic criteria for decision-making and implementing improvement projects for catchment sources management.

Analysis of the results, according to the weighted sum method, determined the priority levels of the scenarios as related to the overall objective. In most parts of the study area, scenario 8 received the highest score; it was ranked first, followed by scenario 7. This means that the stakeholders of the Darenari catchment are interested in improving rangeland areas. The highest priority of scenario 8 was directly related to social criteria, especially incomes from working in suggested activities. Scenario 5 was identified as the third priority, making it higher in priority than scenario 6, because of the effects of the sowing implementation area, which included about 42% of the total research area. In fact, the effects of the implementation of scenario 5, which included sowing activities on four indices (ecological, social, physical, and income), was more effective.

4. Conclusion

From the overview and vital reviews of MCDM explained in the last parts of this manuscript and the discussion regarding other possible approaches, it is obvious that MCDM suggests an appropriate decision-making and planning structure for catchment resources management. Because it is essentially robust, it is also able to supply a suitable framework that serves well in connecting the gap between the more structured and analytical quantitative approach and the soft qualitative planning approach. Methods that incorporate these two paradigms suggest some promise of more suitability in accommodating the essential complications of catchment resources management, including biophysical, ecological, and socioeconomic aspects, and capturing the multitude of considerations, problems, and aims of catchment dependent communities and stakeholders. Preliminary attempts at such integration have shown that this method has a very promising potential.

Belton and Stewart [83] proposed that an integrating structure must identify common components among methodologies and clarify the strengths of each. Mingers [84] also suggested a multi-methodology structure that is capable of mixing, connecting, combining, or integrating various methodologies and paradigms. Li et al. [31] recognized the fuzzy AHP technique as an effective approach to evaluate environmental vulnerability. They stated, however, that this method still needs improvement to further decrease subjectivity in judgments due to the high sensitivity of assessed outcomes to the weights used.

The consequences of implementing management scenarios for catchment sources management may appear in various spatial patterns of land cover. The MCDM approach is a suitable method for dealing with the variability associated with land cover patterns resulting from management performance [14].

In applying a scenario-based method for catchment management, the applied models must be capable of predicting the consequences of implementing various actions on the catchment scale. Results of the current research showed that the SCS–CN model is able to predict the consequences of vegetation improvement on total discharge. The social consequence analysis using the binomial distribution prepares a probability distribution function for analyzing community opinions about each action and scenario. The results of the ecological consequences assessment showed that WLCAI as an index for evaluating ecological criteria is a suitable approach for explaining changes in patch size and shape and the spatial configuration of patches resulting from management scenarios into better or worse ecological consequences.

Criteria selection and determination are directly related to national and regional strategies. Thus, to apply the achievements of the current research, these strategies must be taken into consideration. This guarantees the suitability and feasibility of the consequences. This approach occurs with the fact that catchment systems are dynamic and complicated, and it is not an easy task to capture all of the disciplinary elements involved in management of natural resources catchment-wide.

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