



# The application of multi-attribute decision making methods in integrated watershed management

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Accepted: 30 August 2023 / Published online: 8 October 2023

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## Abstract

The present investigation has centered on examining the impact of vegetation-based management strategies on the socio-economic, physical, and ecological aspects of the Aghsu watershed in Golestan province, with a particular emphasis on mitigating soil erosion and flooding issues. This study implemented four biological interventions (namely contour furrows with seedling planting, reforestation, channel terraces with tree planting, and agroforestry) and identified 16 management scenarios based on the managerial issues of the area. To establish a hierarchy of management scenarios, the techniques of TOPSIS, SAW, linear assignment, and VIKOR were employed, in conjunction with four distinct weighting methodologies (namely, Shannon Entropy, AHP, ANP, and adjusted weight). The Borda method has been employed to amalgamate the ranking of the suggested technique. Based on the results obtained from all proposed methods for prioritizing scenarios, it has been confirmed that “Scenario 1” holds the lowest priority. The findings indicate that “Scenario 3” (Agroforestry) and “Scenario 6” (Agroforestry and Contour furrows with planting of seedling) represent the optimal scenario groups. The findings indicate that the amalgamation of two scenarios and scenarios that incorporate Agroforestry exhibit superior outcomes. The implementation of agroforestry is a noteworthy endeavor that warrants heightened attention, with other management pursuits being regarded as secondary priorities. Moreover, it can be asserted that the precise weighting of evaluation criteria plays a crucial role in prioritizing management scenarios. The precise computation of weights is imperative. The utilization of a scenario-based methodology in this study facilitates the prediction of the potential outcomes of biologic management interventions. The utilization of this methodology is postulated to enable watershed planners and stakeholders to select the optimal scenario from the proposed set of management scenarios.

**Keywords** Aghsu watershed · Multi-attribute decision making · Integrated watershed management

## 1 Introduction

The destruction of the watershed and the hydrological variation of the river lead to decreased water quality and change in the discharge rate. Therefore, watershed management programmes should be based on a comprehensive and integrated management approach (Sarangi et al. 2004; Miller et al. 2004; Gajbhiye et al. 2015; Ikram et al. 2022a, b). Integrated watershed management is a method that enables the comprehensive management of water and land and other environmental resources with the aim of increasing economic and social benefits (Cai et al. 2003; Sekara et al. 2012; Meshram et al. 2017; Meshram et al.

2022c, d). In the past decades, decisions on water resources management problems and choosing the best option to solve the difficulties of a watershed were based only on the transformation of social and economic criteria into economic criteria. But today, using multi-attribute decision-making methods, different quantitative and qualitative criteria can be used to prioritize and select the best option in watershed management (Liu et al. 2015).

When the criteria conflict with each other, resolving multi-attribute decision problems is complicated. The desirability of one can decrease the desirability of another. For this purpose, particular Multi-Attribute Decision Making (MADM) methods were developed to help dissolve these problems (Asgharpour 2006). Multi-attribute decision making methods have a variety of techniques at different

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stages of decision making. A multi-attribute decision problem (MADM) can basically be summarized in a decision matrix, where the matrix rows are different options and the matrix columns are the indicators that define the properties of the options (Li et al. 2018).

In multi-attribute compensatory decision models, all indicators are considered for the ultimate decision and exchanges are made among them. This is what it means that a variation in an index is thwarted by an opposite variation in the index or other indices. Compensatory models are divided into three groups as follows. A: The Scoring subgroup. B: Compromising subgroup is the second subgroup of compensatory models. In the methods related to this subgroup, the preferred option is the one that is the closest to the ideal solution. C: The outranking subgroup is the third subgroup of compensatory models whose output is a set of rankings (Azar and Rajabzadeh 2010).

Compensatory multi-attribute decision-making techniques including SAW, LAM, VIKOR, and TOPSIS were employed in this study. The simple weighting approach (SAW) is one of the simplest multi-attribute decision-making strategies (Ikram et al. 2022c, d; Meshram et al. 2021a, b). This approach is also known as weighted linear combination method. Huang and Yun first proposed this technique in 1981. In this procedure, after standardization and weighting, research alternatives may be prioritized (Sumaizar et al. 2021). The Linear Assignment approach is another multi-criterion decision-making approach that was suggested by Hong in 1983 and subsequently refined by Akgol in 1993. This approach involves modeling a multi-indicator decision problem as a linear programming problem. In this approach, the scales are not normalized or equalized, and any criterion can be used. Issues with disproportional and incompatible criteria can be evaluated using the VIKOR technique, which is based on consensus programming of multi-attribute decision-making issues. The VIKOR method can be proposed as a useful decision-making tool when the decision-maker lacks the ability to recognize and articulate the benefits of a problem during its inception and design (Lin et al. 2021). The TOPSIS is another multi-criterion decision-making approach which was introduced in 1981 by Huang and Yun. This technique uses a set of indicators to rank a set of possible actions. The best solution under this methodology is the one that comes closest to the ideal but is still significantly different from the worst. That is, the best option is the one with the highest profit and the lowest cost, while the worst option has the opposite characteristics (Chen 2019). In Sect. 2.2, further information concerning predictive multi-attribute decision-making systems is offered.

The use of multi-attribute decision-making approaches in different fields has attracted the consideration of many researchers (Pourebahim et al. 2014; Arami et al. 2017;

Meshram et al. 2019a, b, c; Meshram et al. 2020; Meshram et al. 2022a, b; Ghaleho et al. 2020; Yang et al. 2020). Also, many researchers have used multi-attribute decision-making methods in the fields of natural resource management, flood spreading location and land and urban management. Xiong et al. (2022) used the linguistic distance measuring technique and created VIKOR method to evaluate and select green airport designs. Alvandi et al. (2021) proposed a scenario-based approach and multi-attribute decision making method for integrated management of the Bonekoooh watershed -Tehran Province, Iran. The results show that the multi-attribute decision-making method is an extraordinary tool for representation watershed and combining the results of different models to finally make a decision about the obtained results. Chen et al. (2019a, b, c), for better linguistic decision-making under uncertainty, employed a fuzzy TOPSIS technique based on Hamacher aggregation operators and endness optimization models. Vivien et al. (2011) proposed a Fuzzy multi-attribute decision making approach for choosing the best environment-watershed plan. This research has used 5 options for multi-attribute decision making in Taiwan, which indicate the effectuality and utility of the suggested approach. Chen et al. (2019a, b, c) employed an integrated hybrid strategy of PHFLTS and TOPSIS to assess and choose transportation solutions. Chen et al. (2019a, b, c) employed a hybrid MCGDM technique of QFD and ELECTRE III in order to pick sustainable building materials. Kaya and Kahraman (2011) used a Fuzzy multi-attribute decision making forestry decision making method based on an integrated VIKOR and AHP method. In the suggested methodology, the weights of the election criteria are specified by fuzzy pairwise matrices of AHP. Watershed preservation, cost, land availability, soil erosion prevention, political acceptability and social admissibility criteria were considered. Ahmed et al. (2002) developed a decision support system (DSSs) for the choice of optimum water reuse schemes. The results showed that, this system can be used to make fast and reliable decisions for agricultural water management.

The Aghsu watershed is one of the most momentous catchment in Golestan province in terms of erosion, flooding and land use. Considering all factors affecting the watershed together, several strategies to achieve integrated management of watersheds can be evaluated. Due to limited time and resources, prioritizing managerial scenarios is considered important for implementation. In this research, the proposed management scenarios for the Aghsu Watershed have been prioritized according to the compensatory MADM models, so that the scenarios can be prioritized using different methods and the results can be examined. In fact, in this particular case (prioritization of proposed management scenarios of Aghsu watershed in Golestan province), the difference between the results obtained due to changes in the type of multi-attribute compensatory decision-making

methods and different weighting methods has been investigated. Moreover, this research presents the best scenario using multi-attribute decision-making to Gain integrated resource management in the Aghsu area.

## 2 Materials and methods

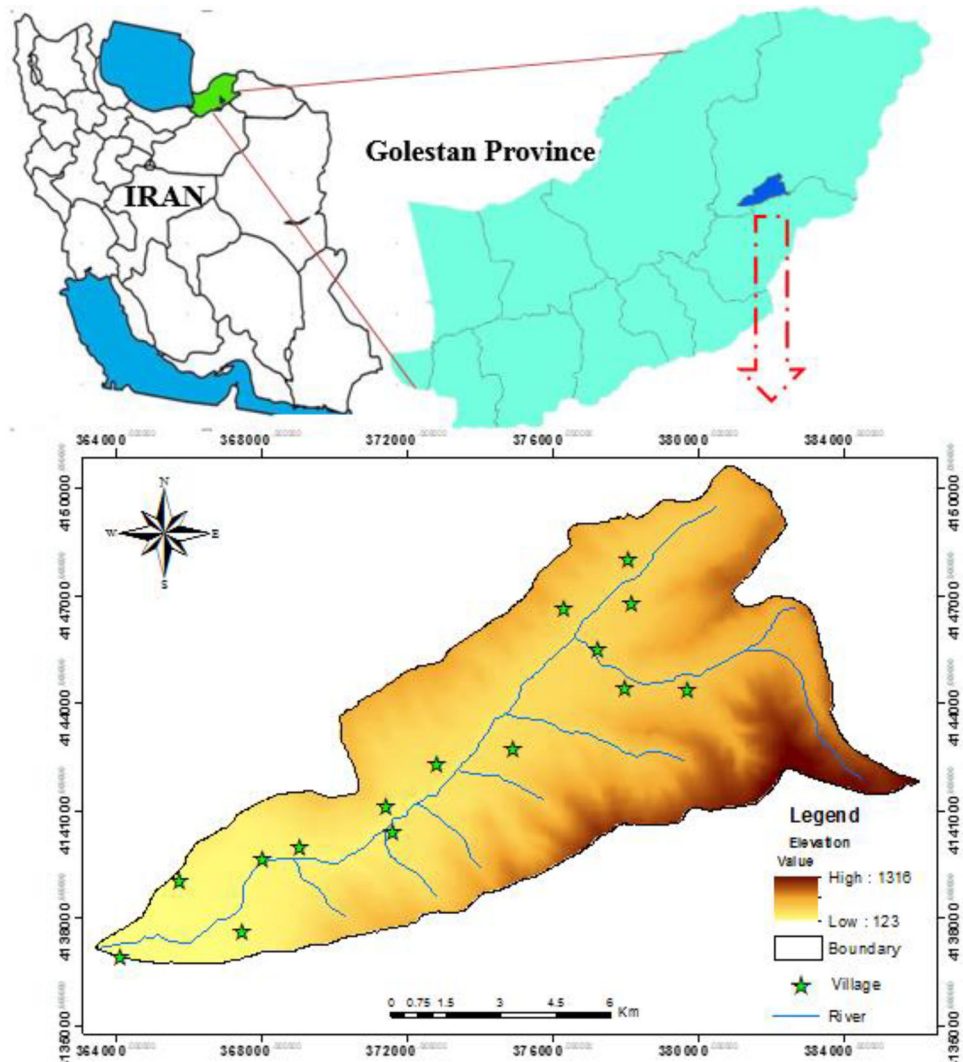
### 2.1 Study area

The Aghsu watershed covers an area of 124.98 km<sup>2</sup>. It is located in zone 40 N, 363,466 m to 386,370 m E and 4,136,972 m to 4,151,333 m N in Kalaleh County in eastern Golestan province. The Aghsu watershed position is shown in Fig. 1. The length of its main stream is 22,358 m. The maximum and minimum elevations are 1359 and 136 m respectively. The concentration time was estimated to be 8.61 h. Its mean annual precipitation is between 571 and 693 mm (Bureau of Natural Resources of Golestan Province

2005). A total of 15 villages and rural areas are located within this watershed. Overpopulation and convenient access to services for some villages in watersheds have resulted in some social and physical discrepancies compared to other rural areas. The Aghsu watershed suffers from various issues, including land use conversion from forest to steep croplands, some geological formations susceptible to grazing pressure, more flooding possibilities, high sediment settling, water erosion, ecological degradation, poor water quality, unemployment; less revenue.

Aghsu watershed has several biophysical, social and economic challenges. This basin is one of the major and at the same time critical basins in terms of land use change, erosion and floods in Golestan province, and for this reason, it has garnered the attention of officials and research departments for further inquiry. Natural forces (such as high slope and floods) and human activities (forest land conversion into agricultural land, inappropriate land-use and farming on high slopes) generate many forms of erosion and

**Fig. 1** Location of the Aghsu watershed, Golestan Province-Iran



mass movements in The Aghsu watershed. With population growth and the increase of human activities, this issue will intensify day by day. Also, the placement of Kalaleh city at the end of this basin necessitates extra care to regulate the flood and its silting. Currently, the existing land-use of the study area is agricultural, woodland, pastures and residential areas (villages). Agricultural fields represent the biggest area of the region, followed by forests. A considerable portion of the basin is covered in broadleaf woods, although much of this natural habitat has been cleared for agriculture, leaving the land vulnerable to erosion because of the basin’s steep slopes and surrounding mountains.

## 2.2 Methodology

The principal purpose of this study is to assess the feasibility of compensatory multi-attribute decision making methods to assess the social, ecological, economic, and physical effects of management scenarios and prioritizing remediation scenarios. The research flow chart is offered in Fig. 2.

### 2.2.1 Identification of causes of issues and formulating management options

In this research, we attempted to model land-use mapping areas as per the Makhdoom model (2010) evaluation of areas of interest. Given the watershed physiographic features, ingredients, units, land property, and limitations (social values, time land fees), in this research,

management actions of contour furrows with planting of seedlings, reforestation, channel terraces with tree planting, and agro-forestry were chosen. According to the watershed features, to execute each of the management actions, susceptible areas must be considered into account (Table 1).

### 2.2.2 Creating of unique management scenarios

Management scenarios with a combination of management actions determine the effects of the scenarios in the watershed. Then, by collecting management-appropriate options in Equation 2n (n is the number of management-appropriate options), a total of 16 scenarios were specified (Table 2). According to the scenario formation rules, land use, soil hydrologic groups, watershed boundary layer, slope, land units, and ingredients in Arc GIS 10.7 software procurement were combined and 16 management scenarios were provided in spatial maps (Figs. 3, 4, 5 and 6).

### 2.2.3 Choice of evaluation determinant criteria

The principal target of choosing the evaluation criterion is to review and elect scenarios by using the best management scenarios. For this purpose, economic, ecological, physical, and social criteria were used in this research. The physical criteria of runoff and erosion rate, the economic criteria of gross income and variable costs, the social criteria of people’s acceptance, and the ecological criteria of biodiversity were selected.

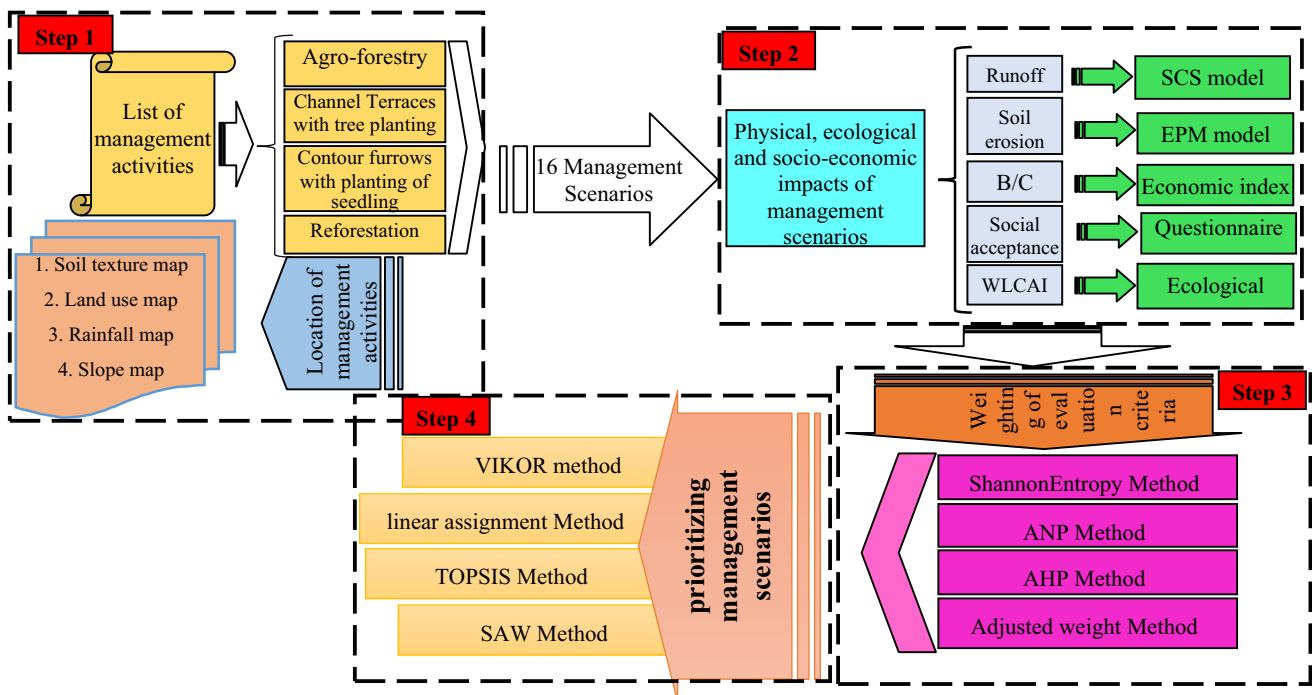


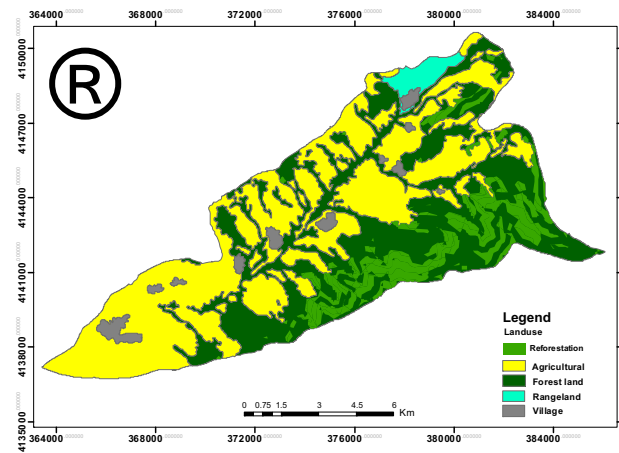
Fig. 2 Methodological framework of the study

**Table 1** Characteristics of studied management activities

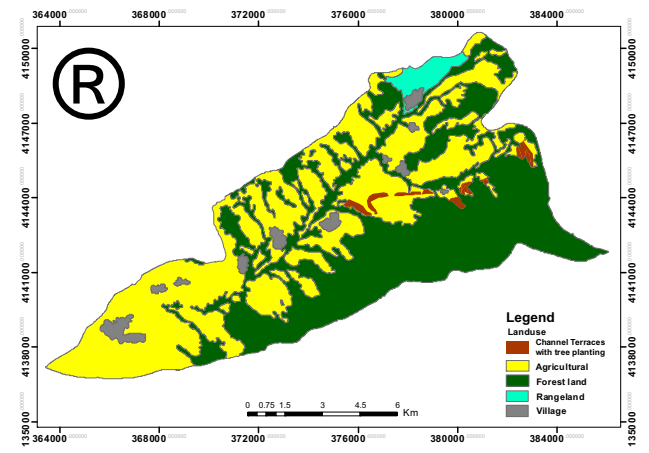
Management activities	Characteristics
Agro-forestry	Cultivated areas, 15–30% slope, semi-deep soil, elevation 200–1600
Channel Terraces with tree planting	Cultivated areas, 10–30% slope, deep soil, elevation 150–800
Contour furrows with planting of seedling	Rangeland areas, 5–10% slope, deep and semi-deep soil, no height restrictions
Reforestation	Low forest density, under to 65% slope, deep and semi-deep soil, under to 1400 m elevation

**Table 2** Management scenarios for the Aghsu Watershed

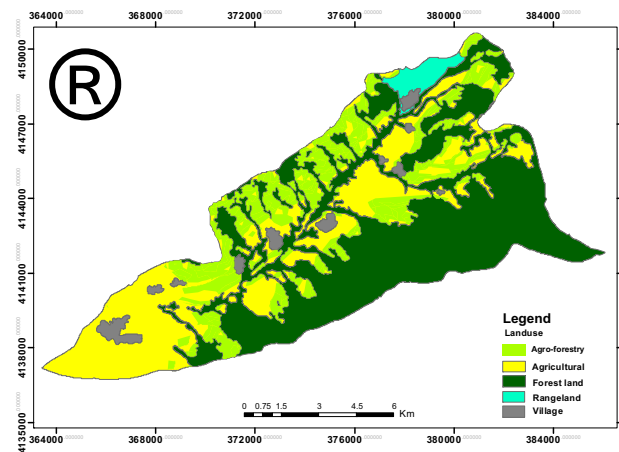
Scenario	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Reforestation		*					*	*	*			*	*		*	*
Agro-forestry			*			*	*				*	*	*	*		*
Contour furrows with planting of seedling				*		*			*	*		*		*	*	*
Channel Terraces with tree planting					*			*		*	*		*	*	*	*



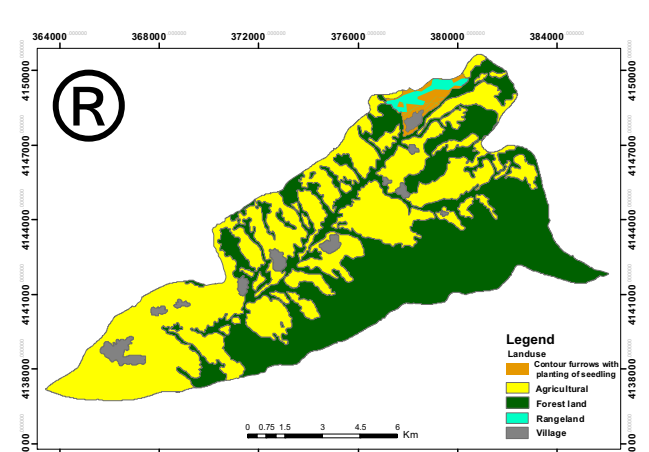
**Fig. 3** Location of the reforestation management activities



**Fig. 5** Location of the Channel Terraces with tree planting management activities



**Fig. 4** Location of the Agro-forestry management activities



**Fig. 6** Location of the Contour furrows with planting of seedling management activities



**2.2.3.1 Modeling the physical outcomes of vegetation-based management scenarios** To investigate the impacts of management on hydrological characteristics, the SCS method was utilized (Rafahi 1999; Alizadeh 2007; Meresa 2019). The EPM model was applied to predict the effects of management practices on erosion (Gavriloic et al. 2004; Efthimiou and Lykoudi 2016).

$$Z = Y \cdot X_a (\psi + 0.5I) \quad (1)$$

where  $Z$  is the rate of erosion,  $Y$  is soil erodibility coefficient,  $X_a$  is land use factor and  $I$  is average slope of the watershed and  $\Psi$  is erosion coefficient.

**2.2.3.2 Modeling the economic effects of vegetation-based scenarios** Two variable costs and gross margins were applied in order to assess the economic impacts of management practices scenarios. Formula 2 was used to estimate the economic effects of management scenarios.

$$G = \sum_{(i)}^n [P_i y_i - C_i] A_i \quad (2)$$

where  $G$  is gross margins essential for activities  $i$  (Rial),  $P_i$  is the price of the products in action  $i$  (Rial),  $y_i$  is yield for  $i$  (Units per ha),  $C_i$  is variable costs essential for activities  $i$  (Rial),  $A_i$  is area of activity defined for  $i$  (ha) and  $n$  is of economic activity (Azkia and Astaneh 2004).

**2.2.3.3 Modeling social outcomes of the scenarios** In this research, the Kokaran equation was used to evaluate the social effects of management scenarios (Azkia and Astaneh 2004) 70 questionnaires were distributed among the residents of one of the villages in the catchment of Aqso. The social acceptance percentage of each of the 16 management scenarios was computed using the binomial distribution method (Alvandi et al. 2021).

$$\text{Pr} = \frac{n!}{m!(n-m)!} P_i^m q_i^{n-m} \quad (3)$$

where  $\text{Pr}$ : possibility of  $m$  acceptance in  $n$  attempts;  $n$ : number of attempts in the binomial test (70 participants);  $m$ : number of acceptance of scenario  $i$  in  $n$  attempts;  $P_i$ : possibility of accepting scenario  $i$  in each attempt;  $q_i$ : the possibility of not accepting scenario  $i$  in each attempt and  $i$ : The scenario number is (1, 2, 3, ..., 16).

**2.2.3.4 Modeling ecological outcomes of the scenarios** To obtain biodiversity according to the WLCAI index under various management scenarios. For this purpose, the units of the scenario and the ecological coefficient of each unit must be calculated with the Delphi algorithm. The WLCAI index equation is as follows (Sadoddin, 2006).

$$WLCAI = \sum_{m=1}^9 \alpha_m \sum_{k=1}^{nm} P_{k,m} \quad (4)$$

where  $\alpha_m$ : weighted values for  $m$  types of land cover  $m$ ,  $n_m$ : the number of patch related to each type of land cover,  $P_{k,m}$ : the size of each patch ( $k = 1, \dots, n_m$ ) (Bai 2011).

## 2.2.4 Prioritizing management scenarios using MADM Methods

According to various economic, ecological, social, and physical criteria and also considering the problems in choosing the best scenario, there is an immediate requirement for multiple attribute decision making (Alvandi et al. 2021). Due to the fact that the values of the criteria are not the same in the scenario and the lack of recognition of positive and negative effects for all criteria, it is useful to use multi-attribute decision making to solve this issue. Table 4 shows the values of these indicators for the 16 proposed management scenarios. Of these indicators that have been proposed to prioritize the scenarios, the social acceptance index, the vegetation area weight index and the cost–benefit index are positive, while the soil erosion index and runoff volume index are negative.

**2.2.4.1 Determining the weight of evaluation indicators** The relative significance of each index was calculated using the value of each evaluation index calculated for 16 scenarios. In the present study, in order to weight each index, we used AHP, ANP, Shannon entropy, and adjusted weight methods. In the AHP and ANP methods, using the viewpoint of 15 experts in the relevant field, the weight of each index was calculated by the pair-wise comparison method. In this method, by forming a matrix that presents the opinions expressed about the comparison of each pair as the decision criterion, finally the relative weight of each index is determined (Saaty 1980).

In this study, the Shannon Entropy method (Eq. 5) was used for quantitative weighting. For this purpose, first the decision matrix  $D$  was created with 16 scenarios and five criteria. This method is based on the  $D$  matrix and uses the  $D$  matrix as the basis for determining the coefficient of importance of the indicators. When the data of a decision matrix (DM) is entirely known, the entropy method can be used to appraise weights (Azar and Rajabzadeh 2010).

$$E_i = S(P_1, P_2, \dots, P_m) = -k \sum_{i=1}^m P_i \ln P_i \quad (5)$$

$$i = 1, 2, \dots, m$$

In this case,  $k$  is a positive constant value, for  $0 \leq E_i \leq 1$  and is calculated using Eq. 6. Since the above equation is used in statistical calculations, it is called the entropy of the probability distribution  $P_i$ .

$$k = \frac{1}{Ln_m} \tag{6}$$

Finally, the estimated weight for each index using Shannon Entropy method ( $w_j$ ) and the weight estimated for each index using AHP and ANP methods ( $\lambda_j, \mu_j$ ), using Adjusted from Eq. 7.

$$w_j = \frac{\lambda_j w_j \mu_j}{\sum_{j=1}^n \lambda_j w_j \mu_j} \tag{7}$$

**2.2.4.2 Standardization of evaluation indicators** In this research, a method for prioritizing scenarios has been selected from each of the compensatory model subgroups. Scenarios are also prioritized using the VIKOR method. In this research, considering that there is a possibility of exchange between the selected indicators to prioritize the scenarios, the desired model has been selected from the compensatory models. Input data in MADM techniques is non-standard data. In the next step, all indicators are converted into a scale and a decision matrix D is formed to compare the scenarios. The data was standardized using scientific methods to make computation and results meaningful. Standardization methods by themselves are not preferable to each other; rather, the processing method will determine the type of standardization method. In order to do so, in the SAW approach, the soft linear method is used to standardize the data (Eq. 8) (Sadoddin et al. 2017).

$$n_{ij} = \frac{r_{ij} - \text{Min}(r_{ij})}{\text{Max}(r_{ij}) - \text{Min}(r_{ij})} \tag{8}$$

In TOPSIS method, Euclidean soft technique is used for data standardization (Eq. 9).

$$n_{ij} = \frac{r_{ij}}{(\sum_{i=1}^m r_{ij}^2)^{\frac{1}{2}}} \tag{9}$$

The linear assignment method does not require standardization of measurement scales, and indicators can be of any scale. Also, in the VIKOR method, the calculation formulas of the fuzzy method are used to standardize the data (Sadoddin and Alvandi 2015).

**2.2.4.3 Prioritization using the linear assignment method**

In the linear allocation method, the hypothetical options of a problem are rated according to their scores for each existing index. And then the final rating of the options is specified through a linear compensation process (for possible exchanges between indicators) (Asgharpour 2006).

In this method, the first rank of each scenario was determined for each of the studied indicators. Then the matrix  $\gamma_{m \times m}$  was extracted according to the weights of each of the indicators. Finally, using the matrix obtained in the previous step, the optimal solution is extracted using a

zero-one programming model and solving this model (Akbarifard et al. 2017).

**2.2.4.4 Prioritization using the VIKOR method**

After data standardization, the VIKOR approach was utilized to prioritize the suggested scenarios. The VIKOR approach is a multi-attribute decision making approach mainly applicable to situations with contradictory and disproportional alternatives (Azar and Rajabzadeh 2010). In this method, the best and worst values of the evaluation criterion are determined by using relations 10 and 11.

$$f_i^- = \min_j f_{ij}, \quad f_i^* = \max_j f_{ij} \tag{10}$$

$$f_i^* = \min_j f_{ij}, \quad f_i^- = \max_j f_{ij} \tag{11}$$

where  $f_i^*$  and  $f_i^-$  are the best and the worst values respectively. At the next step, the maximum group utility of the majority (S) and minimum individual regret of the rival (R) are calculated using Eqs. 12 and 13.

$$S_j = \sum_{i=1}^n w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \tag{12}$$

$$R_j = \max_i [w_i (f_i^* - f_{ij}) / (f_i^* - f_{ij})] \tag{13}$$

where  $w_i$  is the evaluation criteria’s weight. Eventually Q as a compromise solution for S and R, otherwise recognized as the benefit function, is computed from Eq. 14. In the end, ranking and nomination of management scenarios were implemented out (Chang and Lin 2014).

$$Q_j = V(S_j + S^+) / (S^- - S^+) + (1 - V)(R_j - R^+) / (R^- - R^+) \tag{14}$$

where  $S^+ = \text{Min}_j S_j$ ,  $S^- = \text{Max}_j S_j$ ,  $R^+ = \text{Min}_j R_j$ ,  $R^- = \text{Max}_j R_j$  and V is the weight determined by the maximum group consensus.

**2.2.4.5 Prioritization using the SAW method**

In the SAW approach, first the significance coefficient of the indicators is determined, and then, according to the lower decision matrix, the significance coefficient of each management scenario is calculated using Eq. 15.

$$A^* = \left\{ A_i \mid \max \sum_{j=1}^n w_j r_{ij} \right\} \tag{15}$$

where  $w_j$  is the weight assigned to each of the evaluation criteria and  $A^*$  is the most suitable option (management scenario).

**2.2.4.6 Prioritization using the TOPSIS approaches**

In the approach, the scale-balanced is estimated using the weight of each of the matrices. In the TOPSIS approach, the selection option should be the closest option to the positive ideal solution and the farthest option to the negative ideal solution. For this purpose, the ideal positive solution and

the ideal negative solution have been calculated using Eqs. 16 and 17 (Pazand et al. 2012).

$$\begin{aligned} &\text{Ideal Positive Option } A^+ \\ &= \{(\max v_{ij}|j \in J_1), (\min v_{ij}|j \in J_2)|i = 1, 2, \dots, m\} \end{aligned} \tag{16}$$

$$\begin{aligned} &\text{Ideal negative option } A^- \\ &= \{(\min v_{ij}|j \in J_1), (\max v_{ij}|j \in J_2)|i = 1, 2, \dots, m\} \end{aligned} \tag{17}$$

$$A_i^+ = (v_1^+, v_2^+, \dots, v_n^+)$$

$$A_i^- = (v_1^-, v_2^-, \dots, v_n^-)$$

So that

$$J1 = \{1, 2, \dots, n | \text{For the positive elements of indicators}\}$$

$$J2 = \{1, 2, \dots, n | \text{For the negative elements of indicators}\}$$

Then, based on the Euclidean soft, for the ideal negative answer, the size of the distance is calculated using the secret of Eq. 18. And the same and positive size for the ideal solution and the negative option is calculated using the Eq. 19.

$$d_i^+ = \left\{ \sum_{j=1}^n (v_{ij} - v_j^+)^2 \right\}^{\frac{1}{2}} \quad (i = 1, 2, \dots, m) \tag{18}$$

$$d_i^- = \left\{ \sum_{j=1}^n (v_{ij} - v_j^-)^2 \right\}^{\frac{1}{2}}, \quad (i = 1, 2, \dots, m) \tag{19}$$

Finally, the relative vicinity of management scenarios to the ideal solution is computed using Eq. 20, and management scenarios are prioritized according to their distance from the ideal solution.

$$C_i = \frac{d_i^-}{(d_i^- + d_i^+)} \quad (i = 1, 2, \dots, m) \tag{20}$$

### 3 Findings and discussions

In this study, the weight of each indicator has been estimated using Shannon entropy, AHP, ANP, and adjusted weight methods. Table 3 shows the values of these weights.

In Figs. 3, 4, 5 and 6, the location of management activities and the current status of land use for this study are shown. The spatial distribution of suggested management scenarios in the watershed showed that 1203.82, 295.77, 432.92 and 853.48 ha of the catchment, are appropriate for agro-forestry, channel terraces with tree planting, contour furrows with planting of seedling and reforestation, respectively.

The estimated values of the criteria after the implementation of the management scenarios in the Aghsu watershed are presented in Table 4. In terms of soil erosion and runoff criteria, “scenario 16” (reforestation, agro-forestry, contour furrows with planting of seedling and channel terraces with tree planting) had the best scenario and “scenario 1” (protection status quo) had the worst Scenario. But, in terms of social acceptance criterion, “scenario 3” (agro-forestry) had the best scenario and “scenario 1” had the worst scenario. In terms of B/C Criterion, scenario 9 (afforestation and contour furrows with seedling planting) had the best performance in watershed management, and “scenario 5” (Channel Terraces with tree planting) had the worst performance. In terms of ecological criteria, “scenario 16” (reforestation, agro-forestry, contour furrows with planting of seedling and channel terraces with tree planting) had the best performance, while “scenario 1” had the worst performance.

The economic- social and biophysical impacts of all the assessment indicators used in this research for the 16 proposed scenarios are shown in Fig. 7. To calibrate each variable, individually, for each variable the highest value is one and the lowest value is zero. According to Fig. 7, the suggested scenario of “16” has the highest score in terms of “WLCAI” evaluation indices, runoff and soil erosion.

Moreover, prioritization of vegetation management scenarios based on various weighting opinions is demonstrated in Figs. 8, 9 and 10. Figure 8 shows the results of prioritizing scenarios using the SAW method with various weighting methods (Shannon entropy, AHP, ANP and adjusted weight). In this method, the higher the index value of the scenario, the higher the priority scenario, and the lower the scenario, the lower the priority. In all weighting methods, scenario one is the last priority.

In Fig. 9, the results of prioritizing the scenarios by the TOPSIS method with various weighting methods (Shannon

**Table 3** Estimated weight for each of the evaluation indicators

Method	Index				
	Soil erosion	Runoff	Social acceptance	B/C	WLCAI
Shannon entropy method	0.021	0.061	0.706	0.203	0.009
AHP method	0.166	0.185	0.306	0.236	0.107
ANP method	0.127	0.182	0.337	0.258	0.096
Adjusted weight method	0.009	0.024	0.823	0.142	0.002

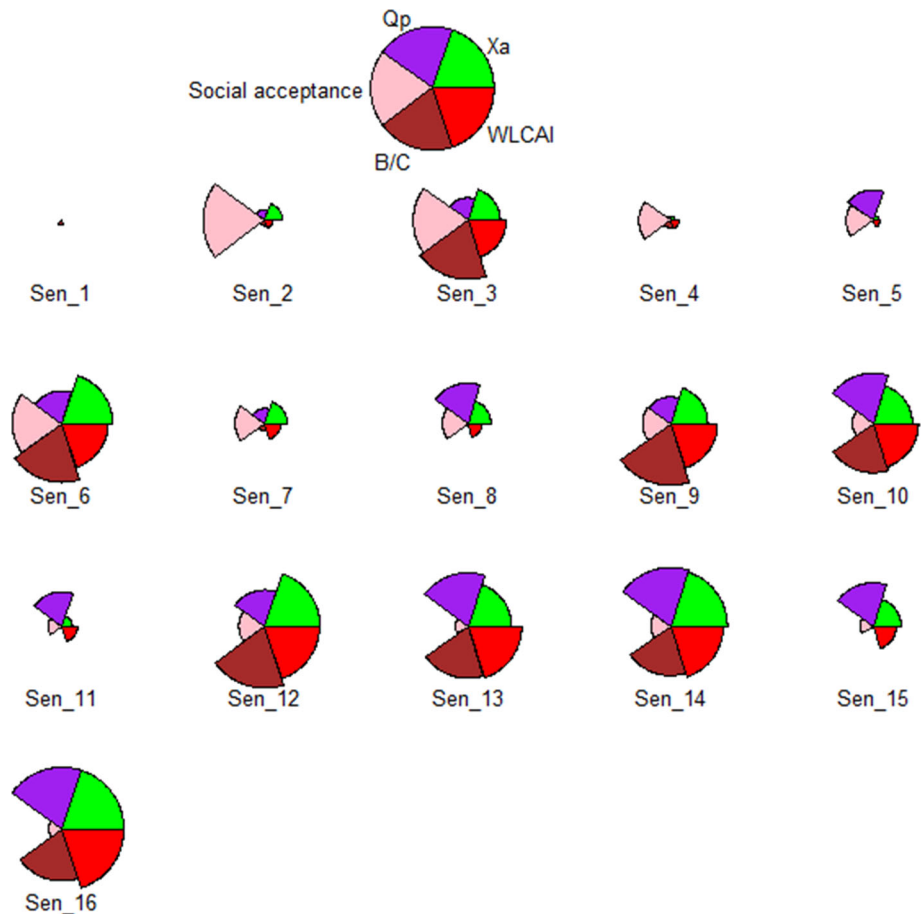


**Table 4** The estimation of criteria after executing management scenarios

Scenario	Runoff	Soil Erosion	B/C	Social acceptance	Ecological
1	<b>309.81</b>	<b>0.47</b>	3.705	<b>10.61</b>	<b>13,399.35</b>
2	290.82	0.451	3.728	71.49	13,523.8
3	270.31	0.435	5.728	<b>91.02</b>	14,031.05
4	302.67	0.465	3.803	71.73	13,541.57
5	256.76	0.464	<b>3.535</b>	75.78	13,513.5
6	253.4	0.416	5.728	75.54	14,155.5
7	284.06	0.446	3.826	49.35	13,666.03
8	240.57	0.445	3.557	43.4	13,637.96
9	263.94	0.43	<b>5.838</b>	46.97	14,173.28
10	223.04	0.428	5.369	37.44	14,145.21
11	250.67	0.459	3.622	29.11	13,655.73
12	247.38	0.411	5.836	44.59	14,297.73
13	217.61	0.423	5.466	26.73	14,287.44
14	208.6	0.409	5.372	36.25	14,269.66
15	234.79	0.44	3.644	27.92	13,780.18
16	<b>203.45</b>	<b>0.404</b>	5.468	27.92	<b>14,411.89</b>

Bold values indicate the minimum and maximum value

**Fig. 7** Impact indicators for management scenarios in the Aghsu watershed



Entropy, AHP, ANP and adjusted weight) are presented. In this method, as in the previous method, the higher the index values of the scenario, the higher the priority scenario, and the lower the index value, the lower the priority scenario.

As it turns out, in all weighting methods, scenario 1 is the last priority.

In Table 5, the results of prioritizing the scenarios by the linear assignment method with various weighting methods

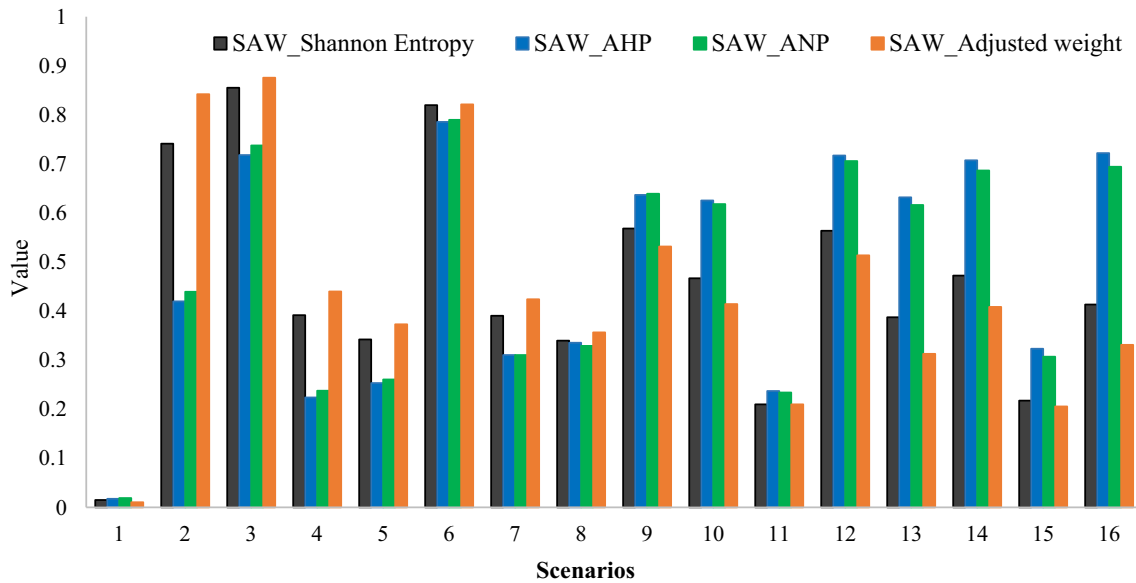


Fig. 8 Prioritize management scenarios by SAW method with different weighting methods

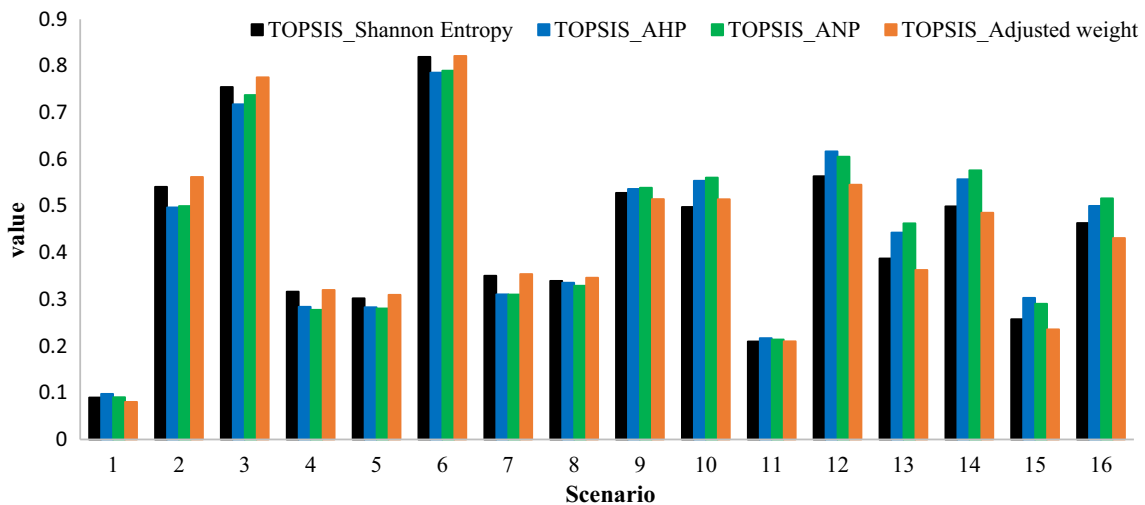


Fig. 9 Prioritize management scenarios by TOPSIS method with different weighting methods

(Shannon Entropy, AHP, ANP and adjusted weight) are presented. Since this method presents the results of prioritization as a matrix, its simplicity is presented in the table below. As it turns out, in all weighting methods, scenario 1 is the last priority.

In Fig. 10, the results of prioritizing the scenarios by the VIKOR method with different weighting methods (Shannon Entropy, AHP, ANP and adjusted weight) are presented. In this method, unlike the SAW and TOPSIS methods, the lower the value of the scenario index, the higher the priority scenario, and the higher the value of the index, the lower the priority of the scenario, as it is clear in this method in all weight methods. Giving scenario one is the last priority.

In Figs. 11, 12, 13 and 14, the results of prioritizing management scenarios with the proposed methods and four different weighting methods (Shannon Entropy, AHP, ANP and adjusted weight) are presented to compare the results. As shown in Fig. 11, the results of prioritizing the scenarios with the adjusted weight in the four proposed methods are close to each other, there are many commonalities between them. However, according to Figs. 12, 13 and 14, in prioritizing the scenarios with the weight estimated by Shannon Entropy, AHP and ANP methods in the four proposed methods, there is a greater difference between the results and the irregularities in these weighting methods.

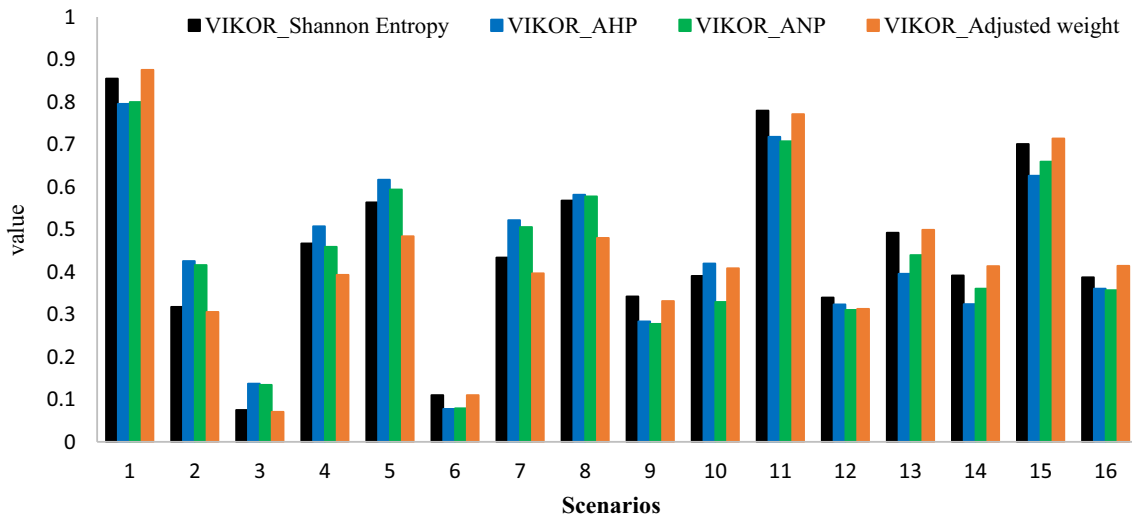


Fig. 10 Prioritize management scenarios by VIKOR method with different weighting methods

Table 5 Prioritize management scenarios by linear assignment method with different weighting methods

Priority	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Shannon entropy method	3	2	6	9	12	10	14	4	7	8	16	13	5	15	11	1
AHP method	6	3	9	2	12	14	10	16	8	13	7	4	15	5	11	1
ANP method	6	3	12	14	9	16	10	2	8	13	7	15	4	5	11	1
Adjusted weight method	3	2	6	9	12	10	4	14	7	8	16	13	5	11	15	1

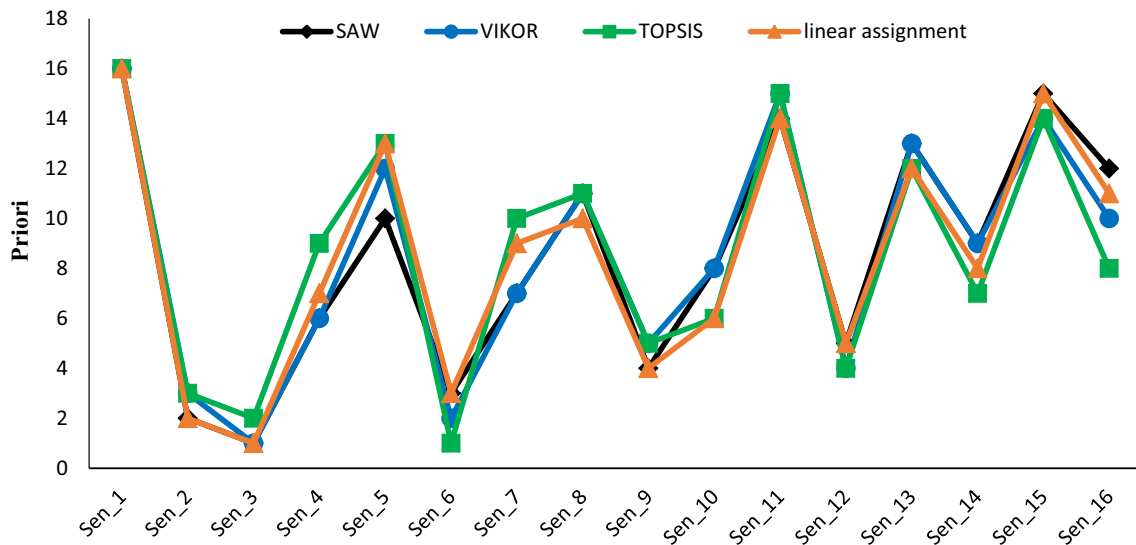


Fig. 11 Prioritize scenarios with estimated weight by adjusted weight method in four proposed methods

Prioritizing of vegetation management scenarios was done by adjusted weight (Fig. 11). Results showed that scenarios 3 and 6 and 2, respectively, were selected as the best management options, among which agro-forestry and contour furrows with planting of seedlings were known as the most suitable.

Using the Borda method, the ranking combination of the suggested techniques for prioritizing the scenarios is done

and its results are presented in Table 6. Using the combined method, scenario one is the last priority.

In these studies, to aid the decision-making process, in order to forecast the effects of management scenarios, different models are used at the watershed scale. The results indicate that the EPM model is necessary to forecast the effect of vegetation change on erosion volume efficiency. While social impacts were evaluated based on

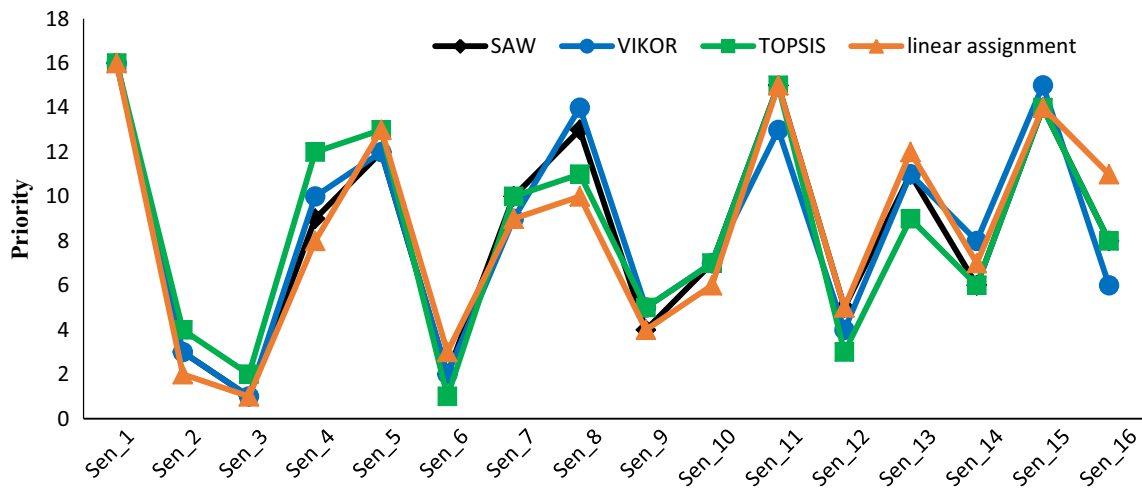


Fig. 12 Prioritize scenarios with estimated weight by Shannon Entropy method in four proposed methods

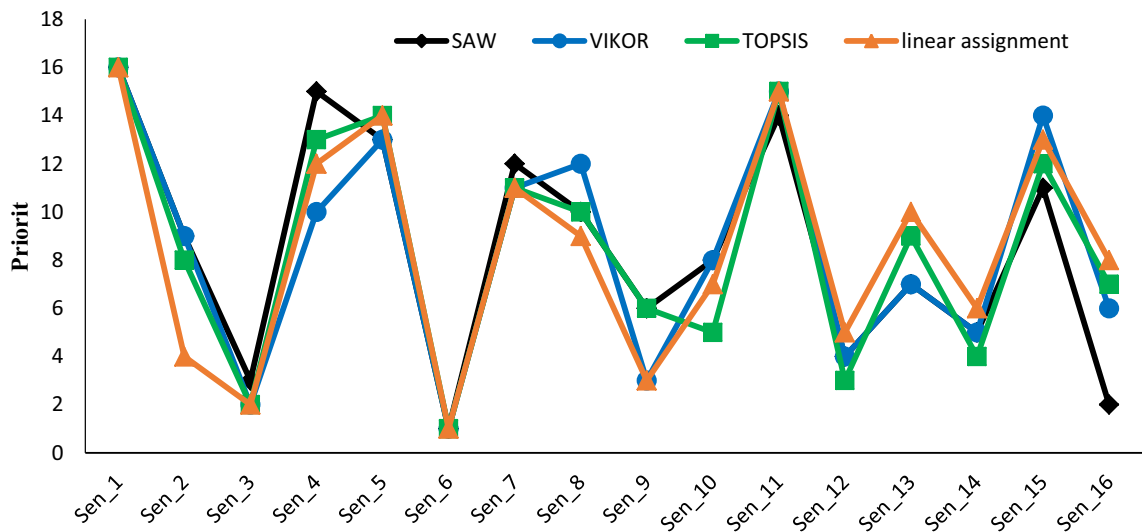


Fig. 13 Prioritize scenarios with estimated weight by AHP method in four proposed methods



Fig. 14 Prioritize scenarios with estimated weight by ANP method in four proposed methods

**Table 6** Combining the rankings of the proposed techniques using the Borda method

Scenario	Sen_1	Sen_2	Sen_3	Sen_4	Sen_5	Sen_6	Sen_7	Sen_8	Sen_9	Sen_10	Sen_11	Sen_12	Sen_13	Sen_14	Sen_15	Sen_16
Shannon entropy method	16	3	1	10	13	2	10	12	5	7	15	4	11	7	14	8
AHP method	16	8	2	13	14	1	11	10	5	7	15	4	8	5	13	6
ANP method	16	8	2	13	13	1	11	10	5	6	15	3	9	5	12	6
Adjusted weight method	16	3	1	7	12	2	8	11	5	7	15	5	13	8	14	10

binomial distribution, this method has been introduced as a suitable tool for evaluating the social acceptance of scenarios. Scenario prioritization assists watershed managers and stockholders in assessing the economic, social, ecological, and physical impacts of proposed management options. Focusing on each of the above criterion will lead to different results. According to the obtained results from all the methods proposed to prioritize scenarios, after the validation of the scenarios, scenario 3 is identified as the final priority. As a result, the agro-forestry scenario has the best results. Moreover, the scenarios including contour furrows with planting of seedling activities are listed as final ones. Based on the results, in this basin, the most important activities are cultivation and forestry, which require more consideration. Other scenarios are in the next priorities. The term “agroforestry” is used to describe a broad category of agricultural and land management strategies in which perennial woody plants are grown in any combination with annual or biennial plants, animals, and/or other non-tree components, in a particular spatiotemporal order. Under these systems, there is a mutual ecological and economic relationship. While the idea of growing trees, food, and animals in close proximity is not new, the current science of agro forestry is. Agro forestry is the practice of combining forest and agricultural practices (Fahad et al. 2022).The method of combining walnut trees and wheat crops has been considered in this study due to the common approach to land exploitation and the allocation of a considerable portion of land to wheat cultivation among crops, as well as the desire to develop fruitful trees, for agroforestry management activity. Table 1 shows the locations in which basin implementation is possible.

Since changing the weight of indicators has significant effects on the prioritization of scenarios. Therefore, the weight of the indicators should be calculated and extracted more accurately. As shown in Table 3, in all weighting methods, the highest weight is assigned to the social acceptance index and the lowest weight is assigned to the ecological index. The high weight of the social acceptance index in all four weighting methods has a significant effect on the prioritization of scenarios in all proposed methods, and changes in this index cause the most changes in the prioritization of scenarios. The weight specified for the criterion has significant effects on the prioritization of scenarios. More attention should be paid to the calculation of important allowances. Therefore, this method can be proposed as an appropriate technique for Integrated Watershed management.

Also, the social acceptance of scenarios by the people is considered an important matter, and for the successful implementation of scenarios, more attention should be paid to the social acceptance of scenarios by the people. Also,



although it seems that both methods (quantitative and qualitative) in determining the weight of the indicators are almost in line, it should not be forgotten that Shannon's entropy weighting method does not meet the internal demands of the decision-maker. This is because this method only pays attention to the internal structure of the data and does not pay attention to the opinions of the decision maker. Therefore, in the Shannon entropy method, due to the changes in the data in the social acceptance index for 16 scenarios, the maximum weight for this index is considered. And due to the similarity of the data in ecological indicators, the lowest weight is considered for ecological indicators. Of course, the simplicity of the entropy method should not be ignored.

As shown in Fig. 8 and Table 5, in SAW methods and linear allocation to the type of weighting method (Shannon Entropy, AHP, ANP and adjusted weight), the prioritization of scenarios shows a significant change. As shown in Fig. 10, in the VIKOR method, the changes resulting from the prioritization of scenarios in different weighting methods are less than in the previous two methods. However, as shown in Fig. 9, the TOPSIS method does not show profound changes in the prioritization of scenarios in different weighting methods (Shannon Entropy, AHP, ANP and Adjusted weight). Therefore, it can be said that the TOPSIS method has shown more stability against changing the weighting method, which is consistent with the statements of Judge Alvandi et al. (2021) in this field.

The quality of management decisions is crucial to the success of a business in achieving its objectives. Taking appropriate management action in a given region entails making a one-of-a-kind alteration to the preexisting system in order to shift current conditions in the direction of the desired outcome. In the Aghsu watershed, the forest areas are being destroyed and incorrect agriculture on the steep slopes has led to an unsatisfactory hydrological state in the watershed. When the recommended management methods are put into place, however, the soil conditions of the Aghsu watershed improve in terms of drainage and plant establishment. The exposed regions will be protected by the increased plant cover, and the hydrological system will be more stable. The structure of the Aghsu watershed has shifted as a result of management operations leading to the development of new spatial patterns of vegetation. Therefore, in order to validate the outcomes of the scenarios, it is required to compare these models to the baseline scenario (the existing state of affairs). The physical, ecological, economic, and social criterion indicators that were studied were used to anticipate the results of adopting several management scenarios in the Aghsu watershed and to choose the optimal scenario or scenarios. With the aid of the scenario development, managers, planners, and watershed operators will be able to know the outcomes of many

conceivable actions based on the current priorities and restrictions, before carrying out any activity and incurring the costs and consequences. This allows for deliberate scenario choice using a comprehensive management strategy. In reality, the multi-attribute decision-making method streamlines the decision-making process by providing executive priorities to managers and planners.

## 4 Conclusions

This study aims to evaluate and prioritize management measures at the basin level using multi-attribute decision-making approaches as a highly relevant and accurate instrument, and improve decision-making with the help of the mathematical sciences and optimization. Mathematical reasoning and multi-attribute decision-making procedures are preferable for prioritizing management initiatives in light of budget and time restrictions. This research can have significant effects on stakeholder participation in watershed management plans. Decision-making approaches can be used as useful tools in watershed management. This reduces prioritization costs. The decision-making approaches used in this study can forecast the effects of biologic management action. It is assumed that using this approach, watershed planners and stakeholders can choose the best scenario among suggested management scenarios. Therefore, with the investigations carried out in the Aghso catchment to achieve better results, there should be more communication and coordination between watershed residents and decision makers.

One of the main sources of uncertainty in this research arises from insufficient access to data and information which could question the findings of any research. The economic impact assessment of different management scenarios is one of the factors investigated here. However, given the scarcity of reliable data, it was necessary to rely on the speculation and expert opinion of subject matter specialists in order to evaluate the economic implications of potential management scenarios. For instance, at the conclusion of each period, 25% of the revenue from wood sales is assigned to extraction and maintenance expenditures in the tree plantation management activity for each plant. In addition, it was assumed that the cash flow performance of the plants across all scenarios would be the same. Here, it is assumed that plant development is more rapid in the middle phases of growth and slower in the early stages. In keeping with the findings of the study, the following recommendations are given:

- Changing cultivation patterns on agricultural fields is one strategy recommended to decrease erosion, boost fertility, and, by extension, increase revenue. These

might be useful for future research and to consider when creating management scenarios.

- By educating residents of the watershed through promotion courses and enacting incentive policies, it is hoped that they will be more receptive to the proposed activities, which will increase their acceptance and cooperation in the plans and implementation of management measures.
- It is recommended to regularly design programs to monitor the progress and implementation of the project.
- For evaluating the efficacy of measures in minimizing watershed concerns, it is suggested that the project achievements be assessed and reported regularly.
- More time and effort should be spent on running promotional courses and inform the watershed inhabitants about the benefits of these measures in order to boost public interest in the tree planting scenario and to protect the natural environment.
- Comprehensive watershed management studies can benefit from this method since it allows the implementation division to save money, time, and effort while still monitoring the outcomes of their efforts.
- It is suggested that the implementation department use this approach in comprehensive watershed management studies to lower cost and time requirement and to evaluate the outcomes of the projects.

**Acknowledgements** The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University, Abha, Kingdom of Saudi Arabia for funding this work through Large Groups RGP.2/209/44.

**Author contributions** All authors all equally contribute in the manuscript.

**Funding** Deanship King Khalid University, Kingdom of Saudi Arabia.

## Declarations

**Conflict of interest** All Authors declares that they have no conflict of interest.

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

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