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# Comparison of Compensatory and non-Compensatory Multi Criteria Decision Making Models in Water Resources Strategic Management

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**Abstract** Growing water demands as well as inconsistency between water demand and water supply pose new challenges for water resources managers in arid regions. This study examines the strategies to tackle water shortage for a sustainable development in Shahrood, Iran. A contentious plan has been proposed to transfer water from the Caspian Sea in north of Iran to this region. Ensuring sustainable development, however, necessitates a strategic planning for water resources. The study develops all viable strategies for the region using Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. Due to inability of the SWOT model to rank the alternatives, the developed strategies are ranked using Multi Criteria Decision Making (MCDM) models based on specified sustainable development criteria. The ranking is implemented using the compensatory models of Simple Additive Weighting (SAW) and Analytical Hierarchy Process (AHP), and the non-compensatory model of ELimination and Choice Translating REality (ELECTRE III). The results of all MCDM models introduce water transfer as the worst strategy for the region. Because of the uncertainty in the relative importance of specified criteria, sensitivity analysis is done for MCDM models by altering the criteria weights. The results show that the ELECTRE III method has lower sensitivity than the SAW and AHP methods to changes in the weights. Also, the compensatory methods exhibits a high dependency to the weights of some dominant criteria. Therefore, this research reveals that the rankings obtained from the ELECTRE III method are more reliable for decision makers to ensure a sustainable development in the region.

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## 1 Introduction

Water crisis is becoming a great challenge especially in arid regions. This necessitates supply-demand coordination in water resources management to balance water demands and supplies. This coordination requires an integrated water resources management through strategic planning. Strategic planning takes into account all policies, stakeholders' opinions, and available resources to prevent critical long term conditions and to ensure the continued advancement of sustainable water resources management (Yüksel & Dagdeviren, 2007).

The first step in strategic planning is developing relevant strategies. The Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis is a commonly used method that provides an appropriate basis for successful strategy formulation. SWOT analyzes the most important internal (i.e. strength and weaknesses) and external (i.e. opportunities and threats) factors in the system to develop the strategies capable of providing a good fit between these factors. However, SWOT does not consider the factors' relative importance and merely suggests some strategies without providing an analytical ranking to determine the priority of the developed strategies (Hill & Westbrook, 1997). To resolve this shortcoming, Kurttila, Pesonen, Kangas, and Kajanus (2000) utilized a hybrid model by integrating a SWOT analysis with a Multi Criteria Decision Making (MCDM) model.

In MCDM analyses, appropriate relative weights are assigned to decision criteria to represent their importance in the system. The combined effect of all decision criteria creates the overall performance of strategies. Two categories for MCDM analyses are compensatory and non-compensatory methods. In compensatory techniques, poor performances of a strategy in some criteria can be compensated for by high performances in some other criteria; therefore the aggregated performance of a strategy might not reveal its weakness areas. Simple Additive Weighting (SAW) (Hwang & Yoon, 1981), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Srdjevic, Medeiros, & Faria, 2004), Analytical Hierarchy Process (AHP) (Saaty, 1980), and Fuzzy AHP (Banihabib & Shabestari, 2016; Mikhailov, 2004; Srdjevic & Medeiros, 2008; Tsakiris & Spiliotis, 2011; Yang, J-h, & Hou, 2013) are some examples of compensatory techniques. In contrast, in non-compensatory techniques, significant poor performances of a strategy in some criteria cannot be compensated for even with very high performances in other criteria, and the aggregated performance reflects this fact (Kangas, Kangas, & Pykäläinen, 2001). In other words, each individual criterion can independently play a crucial role in aggregated performance of a strategy. ELimination and Choice Translating REality (ELECTRE III) is an example of this technique (Roy, 1968). Jeffreys (2004) provides a review of MCDM compensatory and non-compensatory techniques. Applications of MCDM methods have demonstrated their promising capability in water resources management (Abrishamchi, Ebrahimian, Tajrishi, & Mariño, 2005).

Ho (2008) reviewed the application of AHP in different fields and concluded that the integrated AHPs, including integration with SWOT, can provide a more realistic decision than the stand-alone AHP. Integration of SWOT with AHP has also been used for decision analysis in water resources management. Gallego-Ayala and Juízo (2011) combined SWOT and AHP techniques to identify and rank the important factors for the success of integrated water resources management in Mozambique. Chitsaz and Banihabib (2015) examined various

MCDMs for ranking flood management alternatives. Still, incorporating compensatory and non-Compensatory MCDMs based on sustainable development criteria can be involved for promoting SWOT in strategic planning of water resources.

In this study, we use SAW, AHP, and ELECTRE III methods to rank the strategies developed by the SWOT model. The results are compared to appraise the reliability of the rankings. Finally, sensitivity analysis is implemented to assess the stability of the rankings obtained from different MCDM methods. This research aims to demonstrate the capabilities of compensatory and non-compensatory decision making models via a comparison of their outcomes for a water resources strategic planning in an arid region.

## 2 Materials and Methods

### 2.1 Study Area

Shahrood is a city in Semnan Province in the north eastern part of Iran and is used as the study area (Fig. 1). The city is located in the north part of Dasht-e Kavir Basin, a large desert lying in the middle of the Iranian plateau, with an arid climate.

The meteorological data (for years 1951 to 2015) obtained from Shahrood climatology station shows that temperature varies from −8.6 to 20.6 °C with an average of 14.5 °C, and humidity average is %48. Also, the precipitation minimum, maximum, and average values are 104, 442, and 154 mm, respectively. (Banihabib, 2009). There is no perennial river in the region and all the rivers are seasonal and ephemeral. These low-flow rivers exist only during high precipitation periods and eventually discharge to Dasht-e kavir Desert. On the other hand, as the result of excessive groundwater extraction, negative water balance has been observed in all aquifers in the region which puts the groundwater resources in grave danger of losing sustainable water supply (Banihabib, 2009).

Despite of these challenges, the region has several strengths which can be used in strategic planning of water resources. There are 1679 wells and 373 Qantas in the region capable of supplying water to the agricultural, industrial and service sectors (Banihabib, 2009). Also, there is a potential for implementing artificial recharge plans. With 33 mines and 51 industrial

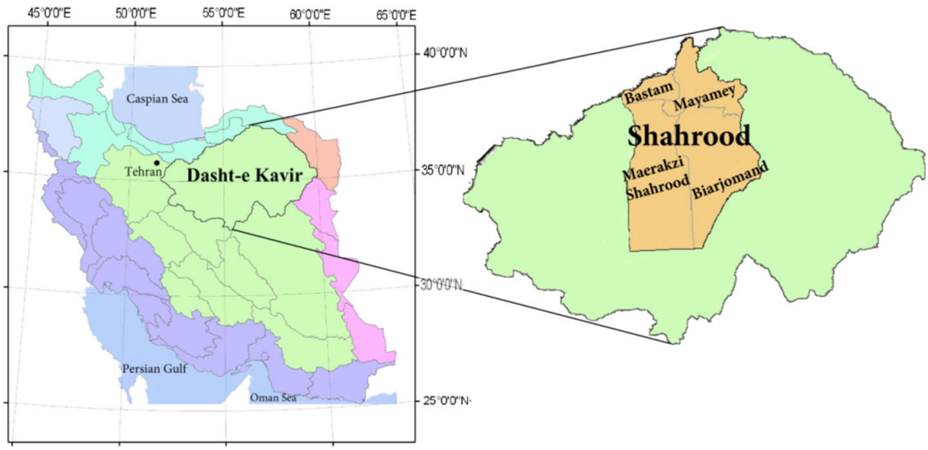


**Fig. 1** Location of Shahrood city, the area used for the study

companies, the region has a potential for growth in mining and industrial sectors. (Banihabib, 2009). The agricultural organizations can develop optimum cropping patterns by consulting with the experts in the region's universities. Existence of many technician and engineers enables employing them to modernize irrigation systems, water supplies, and wastewater treatment plants in the region. In addition, the region is relatively close to Tehran metropolitan (about 400 km distance) which can provide an access to Tehran's consumption market (Banihabib, 2009). These strengths should be part of water resources management strategies in the region.

As one of the several proposed strategies, the presence of abundant water supplies in some parts of the country has impulsively introduced water transfer as the "permanent" solution to resolve water shortage issue in the region. An integrated water resources management, however, needs to systematically identify all potential alternatives and evaluate their viability. As a case study, we demonstrate this goal for the city of Shahrood.

## 2.2 Methodology

In this study, in order to identify and rank the strategies, we first need to define a development vision plan for the area. The alternative strategies to achieve sustainable development are identified by the SWOT model. Compensatory and non-compensatory MCDM models are employed to rank the alternatives based on the specified criteria of the development vision. Sensitivity analysis is implemented on MCDM models to evaluate the effect of uncertain weights of different criteria. In conclusion, the best strategies to satisfy the objectives of development vision are introduced (Fig. 2).

### *2.2.1 Region's Development Vision*

Identifying the development vision is the most important aspect of water resources planning which guides sustainable development in long term through feasible operational activities. Kotter (2012) stated that the development of a vision will be effective if it is future-focused, achievable, inclusive, clear, and flexible. Based on these characteristics, development vision plan for Shahrood is defined as follows:

The city will potentially have sufficient supply of water capable of the optimal satisfaction of municipal, industrial, and agricultural demands while preserving groundwater resources by implementing the optimal strategies. The optimal strategies will also be able to provide the opportunity for economic growth while keeping the environment clean. The city will be pleasant for life, business and recreation for all citizens who have a high level of involvement to achieve sustainable development for their city by implementing the optimal strategies.

### *2.2.2 SWOT Analysis*

The steps in SWOT analysis are:

- Gathering relevant information and data about the study area
- Establishing a group of region's water experts (water resources managers and university professors)
- Preparing a report and presenting it to the water experts to make them familiar with region's water conditions

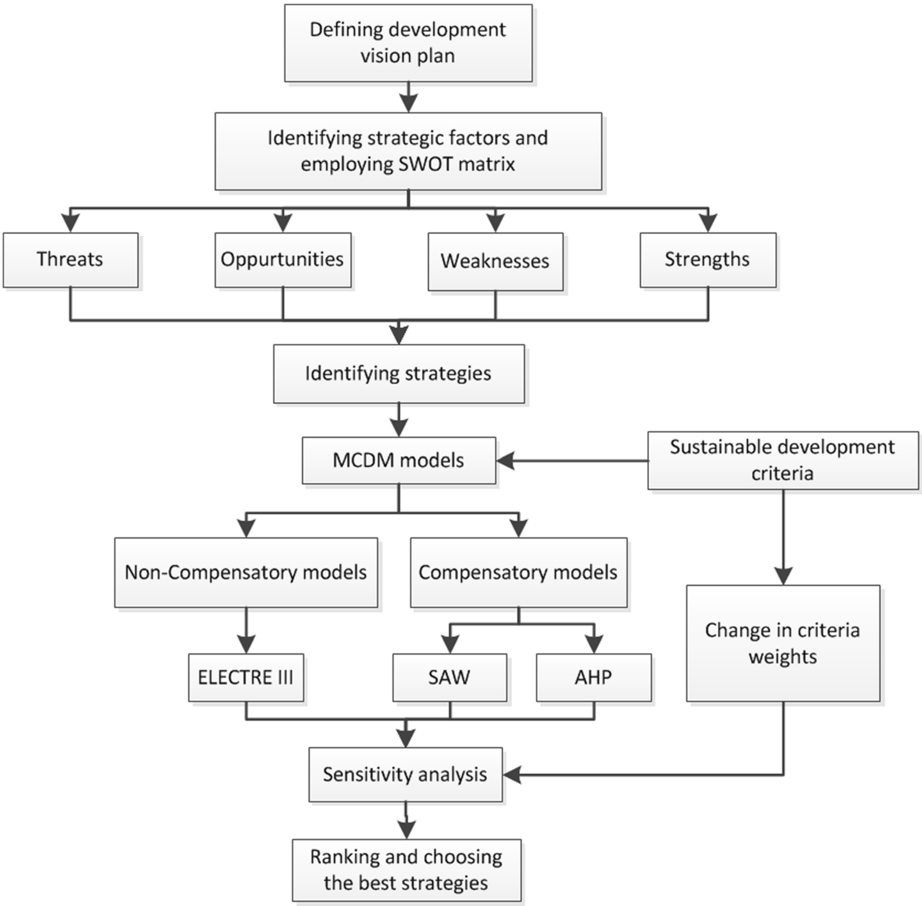


**Fig. 2** The methodology to identify and rank the viable strategies for a sustainable development

- Holding a brainstorming session to identify the strengths, weaknesses, opportunities, and threats of the system
- Creating a SWOT matrix
- Developing aggressive, conservative, competitive, and defensive strategies

### *2.2.3 Sustainable Development Criteria*

Although there are different definitions for sustainable development in different projects, some characteristics such as considering environmental, technical, social, and economic aspects are common among them. The sustainable development criteria in this study are chosen consistent with recommendations of international standards (Banihabib, Azarnivand, & Peralta, 2015; Hazeltine & Bull, 2003; United Nation (UN), 2000; United Nation Development Program (UNDP), 2008). The criteria to address the objectives of this study are as follows:

Criterion 1 (C1): Economy.

Criterion 2 (C2): Acceptability.

Criterion 3 (C3): Protection of environment;
Criterion 4 (C4): Effectiveness.
Criterion 5 (C5): Feasibility.
Criterion 6 (C6): Flexibility.

*2.2.4 MCDM Compensatory and non-compensatory Methods*

As mentioned, in this study, compensatory techniques of SAW and AHP and non-compensatory technique of ELECTRE III are used to rank the developed alternatives. In this section, we demonstrate the details of these techniques.

**Simple Additive Weighting (SAW) Method** For a system with *m* criteria and *n* strategies, a performance matrix is created which shows the efficiency of each strategy to address each criterion. The aggregated score (AS) of each strategy is calculated using Eq. 1 (Hwang & Yoon, 1981).

$$AS_i = \sum_{j=1}^{m} w_j r_{ij} \tag{1}$$

where $w_j$ is the weight for criterion j, $r_{ij} = \frac{x_{ij}}{X_j^{Max}}$ are normalized values of the performance matrix, $x_{ij}$ is the performance score of strategy *i* according to criterion *j*, and $X_j^{MAX}$ is the maximum value of $x_{ij}$ for criterion *j*. The best strategy is the one with highest aggregated score.

**Analytical Hierarchy Process (AHP) Method** The AHP model begins by arranging the elements of the analysis in groups of objective, criteria (and sub-criteria, if available), and strategy alternatives. In the first step, a pairwise comparison of criteria is performed by decision makers. So, decision makers can focus only on two factors at a time. The subjective judgments are translated into a quantitative score using a discrete 9- point scale as suggested by Saaty (1980). The results of the pairwise comparison of different criteria are arranged in a matrix and Eigenvector method is used to calculate normalized principal Eigen vector which is actually the priority weight of each criterion against the system's objectives. After determining the weights of criteria with respect to system's objectives, the same procedure is implemented to determine the weights of strategies with respect to each criterion. For each criterion, the strategies pairwise comparison matrix is then constructed and Eigenvector method is used to obtain the priority weight of each strategy. Finally, aggregated score of each strategy is calculated by Eq. 2:

$$AS_i = \sum_{j=1}^{m} w_j a_{ij} \tag{2}$$

where $w_j$ is the priority weight for criterion j, and $a_{ij}$ is the priority weight of ith strategy in jth criterion. To address the study's objective, the criteria pairwise comparison matrix is determined by the experts committee of this research and the Eigenvector method is used to obtain the priority weight of each criterion. These priority weights are employed in all MCDM models in this study. Since the comparisons are based on the subjective evaluations of decision makers, a consistency check is needed to ensure selected weights are reasonable and valid. This check is performed using an index called consistency ratio (CR) proposed by Saaty (1980). Saaty (1980) suggests the minimum acceptable CR to be 0.1.

**Non-compensatory Model (ELECTRE III)** The ELECTRE III method is one of the most powerful methods in MCDM due to its ability in considering thresholds in ranking process. In this model, we define alternatives as $X = \{x_1, x_2, \ldots, x_n\}$, the criteria as $J = \{j_1, j_2, \ldots, j_m\}$, and alternatives' performances regarding jth criterion as $G_j = \{g_j(x_1), g_j(x_2), \ldots, g_j(x_n)\}$. Three thresholds are introduced to express the relations between alternatives more realistically by considering the fuzzy nature of preferences of decision makers. These thresholds are indifference (q), preference (p), and veto (v). To select indifference threshold for a certain criterion, decision makers analyze the difference in performances of different alternatives according to that criterion which does not imply a meaningful superiority. Equations 3 to 5 are used for the determination of these thresholds (Naseri Amin, 2011).

$$q = \alpha_1 g_{j,\min} \tag{3}$$

$$p = \alpha_2 g_{j,\mathrm{avg}} \tag{4}$$

$$v = \alpha_3 g_{j,\max} \tag{5}$$

where $g_{j,\min}$, $g_{j,\mathrm{avg.}}$, and $g_{j,\max}$ are minimum, average, and maximum values of performance matrix according to criterion j, respectively and $\alpha 1$, $\alpha 2$, $\alpha 3$ are threshold multipliers which are determined in this study by sensitivity analysis.

After determining thresholds and criteria weights, construction of two matrices, concordance and discordance, is implemented. The elements of concordance matrix, which are called overall concordance index, for a given pair of alternatives are calculated as (Roy, 1991):

$$c(x_1, x_2) = \frac{\sum_{j=1}^{m} w_j c_j(x_1, x_2)}{\sum_{j=1}^{m} w_j} \tag{6}$$

where $w_j$ is the importance coefficient or weight for criterion j, and $c_j$ $(x_1, x_2)$ is calculated for jth criterion as:

$$c_j(x_1, x_2) = \begin{cases} 1 & \text{if} \quad g_j(x_1) + q_j\left(g_j(x_1)\right) \geq g_j(x_2) \\ 0 & \text{if} \quad g_j(x_1) + p_j\left(g_j(x_1)\right) \leq g_j(x_2) \\ \dfrac{p_j\left(g_j(x_1)\right) + g_j(x_1) - g_j(x_2)}{p_j\left(g_j(x_1)\right) - q_j\left(g_j(x_1)\right)} & \text{otherwise} \end{cases} \tag{7}$$

where $q_j$ and $p_j$ are indifference and preference thresholds for criterion j, respectively. As threshold values of p and q are made smaller, the concordance matrix becomes more symmetric. The elements of discordance matrix, which are called overall discordance index, for a given pair of alternatives are calculated as:

$$d(x_1,x_2)=\frac{\sum\limits_{j=1}^{m} w_j d_j(x_1,x_2)}{\sum\limits_{j=1}^{m} w_j} \tag{8}$$

where $d_j$ $(x_1, x_2)$ is calculated for jth criterion as:

$$d_j(x_1,x_2)=\begin{cases} 1 & \text{if} \quad g_j(x_1)+v_j\left(g_j(x_1)\right)\geq g_j(x_2) \\ 0 & \text{if} \quad g_j(x_1)+p_j\left(g_j(x_1)\right)\leq g_j(x_2) \\ \dfrac{g_j(x_2)-g_j(x_1)-p_j\left(g_j(x_1)\right)}{v_j\left(g_j(x_1)\right)-p_j\left(g_j(x_1)\right)} & \text{otherwise} \end{cases} \tag{9}$$

where $v_j$ is veto threshold for criterion j. Combining concordance and discordance matrices produces what is called a credibility matrix which indicates the degrees of credibility of ranking relationships between alternatives. The elements of credibility matrix are obtained as:

$$S(x_1,x_2)=\begin{cases} C(x_1,x_2) & \text{if } d_j(x_1,x_2)\leq C(x_1,x_2)\forall j \\ C(x_1,x_2)\ .\prod\limits_{j\in J(x_1,x_2)}\dfrac{1-d_j(x_1,x_2)}{1-C(x_1,x_2)} & \text{otherwise} \end{cases} \tag{10}$$

where $J(x_1, x_2)$is the set of criteria for which $d_j(x_1, x_2) > C(x_1, x_2)$.

The final matrix of alternatives is created whose elements are calculated as:

$$T(x_1,x_2)=\begin{cases} 1 & \text{if } \mathrm{S}(x_1,x_2)>\lambda-s(\lambda) \\ 0 & \text{otherwise} \end{cases} \tag{11}$$

where $\lambda$and $s(\lambda)$are calculated using eqs. 12 and 13:

$$\lambda=\max S(x_1,x_2) \quad x_1,x_2\in X \tag{12}$$

$$S(\lambda)=-0.15(\lambda)+0.3 \tag{13}$$

Using the elements of final matrix, descending and ascending *distillation* are employed to develop two pre-orders for the alternatives (Belton & Stewart, 2002). Combining two pre-orders provides the final ranking of the alternatives. As noted, ELECTRE III method only determines ranking of alternative and no aggregated score, similar to SAW and AHP methods (eqs. 1 and 2), is provided for alternatives.

### *2.2.5 Sensitivity Analysis in MCDM Models*

The results of this study are based on criteria weights obtained from subjective opinions of water experts (water resources managers and university professors) in the region. Due to the uncertainty and lack of predefined standards in those judgments, the results can have uncertainty as well. Sensitivity analysis is implemented to evaluate the effect of change in criteria weights on the rankings (Mareschal 1988). Here, we change criteria weights ±20% of their initial estimate. The analysis provides an indication of the uncertainty of rankings obtained from different MCDM methods. The model with least sensitivity to criteria weights is considered as the preferred model.

## 3 Results and Discussion

### 3.1 SWOT Analysis Results

The internal factors (i.e. strengths and weaknesses) and external factors (i.e. opportunities and threats) considered in the study area are summarized in Table 1. From this SWOT matrix, the proposed strategies are classified into four types: aggressive, conservative, competitive, and defensive (Table 2).

### 3.2 Using MCDM Methods to Rank the Strategies

In this section we present the results of ranking the strategies using three different MCDM methods. The results are based on opinions of 40 water experts in the region. As mentioned before, SAW and AHP methods provide one single value as the aggregated score of each strategy. We consider the minimum acceptable aggregated score in these compensatory methods as 50%. Any strategy with a score lower than 50% is considered inconsistent with the objectives of sustainable development and is not recommended to implement.

**Table 1** Internal and external factors of SWOT matrix

| **Internal factors** | |
|---|---|
| Weaknesses | Strengths |
| W1: Lack of modern irrigation systems | S1: Availability of wells and Qanats in addition to resources to develop aquifers artificial recharge plans |
| W2: High water loss and low efficiency in urban water distribution systems | S2: Potential to enhance industry, mining, and ecotourism sections |
| W3: Negative water balance in aquifers due to over extraction and lack of supervision on water resources exploitation | S3: Availability of the resources to develop optimum cropping pattern |
| W4: Absence of cooperation between stakeholders and local agencies | S4: Existence of technical and executive capabilities and potential to employ modern techniques |
| W5: Lack of infrastructure facilities to attract and retain professional human resources | S5: Possibility of wastewater treatment |
| **External factors** | |
| Threats | Opportunities |
| T1: Region's arid and semi-arid climate and desert expansions | O1: Neighborhood with Northern basin and feasibility of using water resources from adjacent basins |
| T2: Absence of expert views to address sustainable development in basin management | O2: Being close to Iran's major cities and availability of transportation networks to access Tehran's consumption market |
| T3: Economic fluctuations and lack of water pricing structure that account for water's true value | O3: Existence of national regulations to address water resources management |
| | O4: Financial supports through loans and financing facilities |

Table 2 SWOT developed strategies

| Strategy | Strategy name | Involved factors | Strategy type |
|---|---|---|---|
| Str1 | Water transfer from adjacent basins | S4-O1-O3 | Aggressive (strengths vs opportunities) strategies |
| Str2 | Water supply through modern techniques such as rainwater harvesting and cloud seeding | S4-O4 | |
| Str3 | Development of modern irrigation systems and teaching the stakeholders optimal utilization | W1-W4-O3-O4 | Conservative (weaknesses vs opportunities) strategies |
| Str4 | Reduction of water loss and improving the efficiency of urban water distribution systems by enforcing relevant regulations | W2-O3 | |
| Str5 | Increasing supervision on groundwater exploitation to prevent over extraction from aquifers | W3-O3 | |
| Str6 | Restoration of aquifers as a drought management strategy consistent with region's arid climate | S1-T1 | Competitive (strengths vs threats) strategies |
| Str7 | Study and implementation of spatial planning, optimal cropping pattern, and industrial growth pattern | S2-S3-T2-T3 | |
| Str8 | Design of wastewater treatment systems as a drought management strategy consistent with region's arid climate | S4-S5-T1 | |
| Str9 | Developing water pricing schemes based on water's true value to encourage stakeholders participation | W4-T3 | Defensive (weaknesses vs threats) strategies |

The first step is to determine the importance weights of six defined criteria. We use AHP method for this purpose. Resulting criteria weights are used in all three MCDM methods. Pairwise comparison of different criteria is arranged in a 6 × 6 matrix and priority weight of each criterion is obtained using Eigenvector method (Table 3). Criterion C3, the capabilities of strategies to preserve environment and maintain environmental balance, receives the highest weight (0.231) and is considered as the most important factor in sustainable development. Table 3 also shows the CR values obtained from comparison matrix of strategies with respect to each criterion.

In the SAW method, for six criteria and nine strategies, we prepare a 9 × 6 performance matrix. The aggregated score of each strategy is calculated using the elements of performance matrix and the weights assigned for each criterion (Eq. 1). The results are shown in Table 4 and Fig. 4. All the strategies achieve aggregated scores of more than 50% and therefore are considered consistent with sustainable development. Str2 strategy (Water supply through modern techniques such as rainwater harvesting and cloud seeding) gains the highest aggregated score and is the best strategy according to the SAW method.

To use AHP method, in addition to the criteria weights, which were obtained for all MCDM methods, the priority weights of nine strategies with respect to each criterion are calculated and

Table 3 Results of criteria ranking

| Criterion name | Criterion | Weight | Rank | CR |
|---|---|---|---|---|
| Economy | C1 | 0.118 | 5 | 0.01 |
| Acceptability | C2 | 0.201 | 2 | 0.02 |
| Protection of environment | C3 | 0.231 | 1 | 0.01 |
| Effectiveness | C4 | 0.184 | 4 | 0.00 |
| Feasibility | C5 | 0.196 | 3 | 0.01 |
| Flexibility | C6 | 0.070 | 6 | 0.02 |

used to compute the aggregated score of each strategy (Eq. 2). The results are shown in Table 4 and Fig. 4. Str4 strategy (Reduction of water loss and improving the efficiency of urban water distribution systems by enforcing relevant regulations) receives the highest score and is considered as the best strategy to address sustainable development objectives. Water transfer from adjacent basins strategy (Str1) is the sole strategy with less than 50% score and therefore is not recommended based on the AHP method.

In the ranking process using ELECTRE III method, we develop a 9 × 6 performance matrix whose elements are $g_j(x)$, performance of alternative x according to criterion j. Thresholds of preference (p), indifference (q), and veto (v) for each criterion are determined using eqs. 3–5. We use four different sets of threshold multipliers (i.e. $\alpha_1$, $\alpha_2$, $\alpha_3$) to analyze the sensitivity of ranking results on these multipliers. Performance matrix, threshold values, and criteria weights are used to construct concordance, discordance, credibility and final matrices to obtain the final ranking of the alternatives. Figure 3 shows the results of strategies ranking for each set of threshold multipliers.

As Fig. 3 shows, Str2 and Str1 are determined as the strategies with the best and the worst rankings in all four sets of threshold multipliers, respectively. However, the selected strategies differ for other rankings. For $\alpha_1 = \alpha_2 = \alpha_3 = 0.1$, Str3 and Str8, Str5 and Str6, and Str7 and Str9 have the same rankings. For $\alpha_1 = \alpha_2 = \alpha_3 = 0.2$ and $\alpha_1 = \alpha_2 = \alpha_3 = 0.3$, Str5 and Str6 and Str9 have the same rankings. The ranking obtained by multipliers of $\alpha_1 = 0.1$, $\alpha_2 = 0.2$, $\alpha_3 = 0.3$ is considered to have slightly better resolution and is used as the representative results of ELECTRE III method to be compared with compensatory MCDM methods (Table 4 and Fig. 4).

Since ELECTRE III method only provides the ranking of the alternatives without their actual score, determining the acceptability of the strategies (based on 50% score) is not possible in this method. Nevertheless, the results of ELECTRE III method suggest water transfer from adjacent basins strategy (Str1), which obtained lower than 50% score in AHP method, as the strategy with the worst ranking.

## 3.3 Sensitivity Analysis on MCDM Methods

Sensitivity analysis is done by independently varying each criterion weight by 20%. The new rankings of strategies only for the cases we observed changes in rankings are shown in Table 5. The SAW method exhibits the most changes in rankings while the ELECTRE III method

**Table 4** Tabular comparison in strategies rankings computed using different MCDM methods

| Strategy | ELECTRE III | AHP | | SAW | |
|---|---|---|---|---|---|
| | Rank | Aggregated Score | Rank | Aggregated Score | Rank |
| Str1 | 7 | 37.41 | 9 | 58.15 | 9 |
| Str2 | 1 | 95.91 | 3 | 100 | 1 |
| Str3 | 3 | 79.59 | 5 | 93.1 | 5 |
| Str4 | 2 | 100 | 1 | 97.8 | 2 |
| Str5 | 5 | 53.06 | 8 | 75.54 | 7 |
| Str6 | 5 | 56.46 | 7 | 66.61 | 8 |
| Str7 | 4 | 88.43 | 4 | 93.41 | 4 |
| Str8 | 2 | 96.59 | 2 | 96.23 | 3 |
| Str9 | 6 | 72.78 | 6 | 86.83 | 6 |

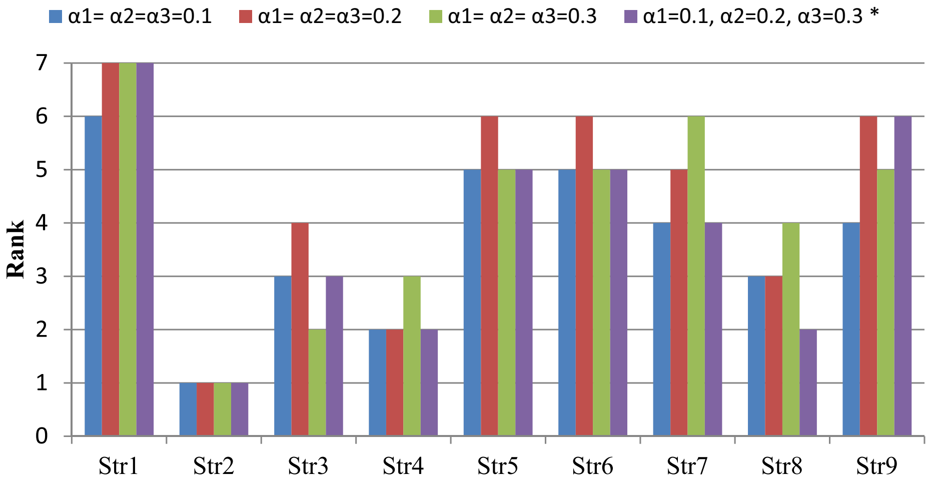


**Fig. 3** Sensitivity analysis on threshold multipliers of ELECTRE III method. * Representative results of ELECTRE III are based on this set of multipliers

shows the least sensitivity and the changes in rankings are less than other methods. The main reason for a more stable ranking by ELECTRE III could be employing three thresholds (indifference (q), preference (p), and veto (v)) which consider the fuzzy nature of decision makers' preferences. Also, the SAW and AHP methods are more sensitive to changes in criteria C2 and C3. That is four out of six cases that we see changes in rankings of SAW and AHP methods, are related to changes in criteria C2 and C3. This is because C2 and C3 have the highest weights among defined criteria (Table 3), and also because of compensatory nature of SAW and AHP methods which have high dependency to these criteria. However, the results of ELECTRE III method are more sensitive to changes in criterion C4 while it does not show any sensitivity to changes in C3 and show less sensitivity to C2 compared with SAW and AHP methods. The lower sensitivity of ELECTRE III method to changes in criteria weights especially to C2 and C3, which reveals the fuzzy nature of the non-compensatory method (ELECTRE III), makes the results of this method more reliable than the results of AHP and

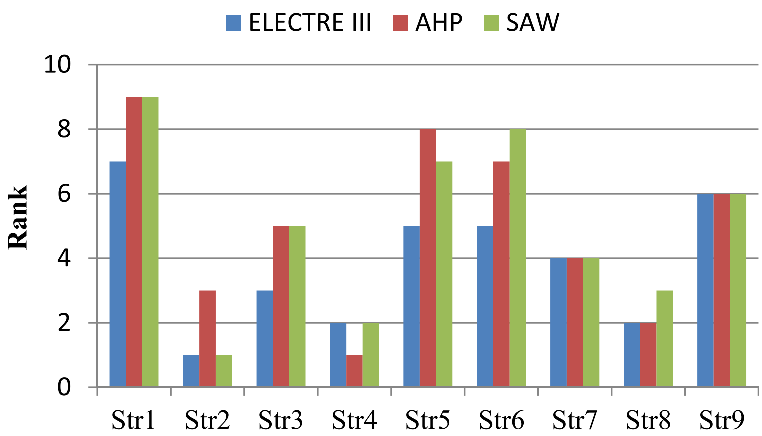


**Fig. 4** Graphical comparison in strategies rankings computed using different MCDM methods

**Table 5** Sensitivity analysis of MCDM methods

| Strategy | AHP | | | | | | SAW | | | | | | ELECTRE III | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.2C1 | 1.2C2 | 0.8C2 | 1.2C3 | 0.8C3 | 0.8C6 | 1.2C2 | 0.8C2 | 1.2C3 | 0.8C3 | 0.8C4 | 0.8C5 | 0.8C1 | 0.8C2 | 1.2C4 | 0.8C4 |
| Str1 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 8* | 6* | 8* | 8* |
| Str2 | 2* | 3 | 2* | 2* | 2* | 2* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2* | 1 |
| Str3 | 5 | 5 | 5 | 5 | 5 | 5 | 4* | 5 | 5 | 4* | 4* | 4* | 3 | 3 | 4* | 3 |
| Str4 | 1 | 1 | 1 | 1 | 2* | 1 | 3* | 2 | 2 | 3* | 2 | 2 | 2 | 2 | 3* | 2 |
| Str5 | 8 | 8 | 7* | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 6* | 5 | 6* | 6* |
| Str6 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 8 | 5 | 5 | 4* | 5 |
| Str7 | 4 | 4 | 4 | 4 | 4 | 4 | 5* | 3* | 3* | 5* | 5* | 5* | 4* | 4* | 5 | 4* |
| Str8 | 2 | 1* | 3* | 3* | 1* | 2 | 2* | 4* | 4* | 2* | 3 | 3 | 2 | 2 | 1* | 2 |
| Str9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 7* | 5* | 7* | 7* |

*Changed rank by sensitivity analysis

SAW methods. Therefore, based on the results of ELECTRE III method in Table 4, water supply through modern techniques (Str2) and water transfer (Str1) are considered the best and worst strategies of this study to ensure region's sustainable development. The economic obstacles as well as environmental concerns may be two main contributing factors for making water transfer the worst strategy for the region.

## 4 Conclusion

In this study, we used the combination of SWOT analysis (to develop the strategies) and three different MCDM methods (to rank the strategies) for implementing water resources strategic planning to achieve sustainable development in Shahrood, Iran. The SWOT matrix was created to identify nine strategies considering internal and external factors including five strengths, five weaknesses, four opportunities, and three threats in the study area. Then, we employed the compensatory MCDM models of SAW and AHP and the non-compensatory model of ELECTRE III to rank the SWOT developed strategies based on six criteria. Based on the AHP method, water transfer strategy gained less than 50% score, the minimum acceptable score of a strategy to be recognized consistent with the objectives of sustainable development. This strategy also gained the lowest score in SAW method and the worst ranking in ELECTRE III method. To evaluate the reliability of the MCDM models results, sensitivity analysis of changes in criteria weights was implemented and showed that ELECTRE III method has lower sensitivity than SAW and AHP methods, especially for changes on the two highest criteria weights. This occurs because ELECTRE III considers the fuzzy nature of decision maker's preferences by applying three thresholds (indifference (q), preference (p), and veto (v)). This implied high dependency of the compensatory methods to the weights of some dominant criteria. Therefore, the results of ELECTRE III are deemed superior in this study for use by decision makers to ensure a sustainable development in the region.

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