Integrated strategic planning and multi-criteria decision-making framework with its application to agricultural water management

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Sustainable water resources management involves social, economic, environmental, water use, and resources factors. This study proposes a new framework of strategic planning with multi-criteria decision-making to develop sustainable water management alternatives for large scale water resources systems. A fuzzy multi-criteria decision-making model is developed to rank regional management alternatives for agricultural water management considering water-resources sustainability criteria. The decision-making model combines hierarchical analysis and the fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The management alternatives were presented spatially in the form of zoning maps at the level of irrigation zones of the study area. The results show that the irrigation management zone No.3 (alternative A3) was ranked first based on agricultural water demand and supply management in five among seven available scenarios, in which the scenarios represents a possible combination of weights assigned to the weighing criteria. Specifically, the results show that irrigation management zone No.3 (alternative A3) achieved the best ranking values of 0.151, 0.169, 0.152, 0.174 and 0.164 with respect to scenarios 1, 4, 5, 6 and 7, respectively. However, irrigation management zone No.2 (alternative A2) achieved the best values of 0.152 and 0.150 with respect to the second and third scenarios, respectively. The model results identify the best management alternatives for agricultural water management in large-scale irrigation and drainage networks.

Water management is becoming more challenging by the effects of climate change, population growth, and severe competition for water by the municipal, agricultural, industrial, and energy sectors1,13,20,24,57. Accordingly, integrated water resources management focuses on water demand and supply management to achieve sustainable development. Water is a scarce resource essential for societal survival and functioning. This makes the application of integrated water resources management essential to cope with scarcity and the challenges posed by climate change and increased water demand to by expanding economies16. A conceptual framework combining integrated landscape management (ILM) and institutional design principles (IDP) perspectives was applied to analyze cooperation initiatives involving water suppliers and agricultural stakeholders from agricultural wastewater5. A national drought risk assessment for agricultural lands taking into account the complex interaction between different risk components was presented40. The research showed that crop diversification, crop pattern management, and conjunctive (i.e., surface water and groundwater) water management can be effective in improving agricultural water18,48.

The management of today's complex water supply and demand systems rely on assessment models combining climatic, social, economic, and environmental factors. A model was developed using the concept of risk by identifying hazards, exposure, and vulnerability11. The vulnerability was classified into two domains, i.e., sensitivity and adaptive capacity, and two spheres, natural/built environment and human environment. A geographical information system modeling and satellite data were developed for water management in agricultural areas by modulating the irrigation water demand based on several vegetation indices9. The water allocation rules were evaluated among water user groups considering environmental, economic, and social criteria involving agricultural water user groups across France11. Transferring of irrigation management was defined as the complete or partial transfer of responsibility for management and investment in irrigation systems from government

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sustainability principles, sustainable agricultural water management at the local level and scale has received less
respect to sustainability practices and goals was discussed. A SWOT analysis consists of well-structured strategic
environmental and social needs while fulfilling the needs of future generations. The lack of strategic vision with
research was applied to achieve the importance of supplier criteria in a combined manner. The fuzzy set in the form of
including the DEMATEL (Decision Making Trial and Evaluation Laboratory) and BWM (best worst method)
was applied to construction site selection, and demonstrated that game theory can be applied for supporting decision
in a competitive environment. SWOT analysis can be improved for decision-making problems. The method was applied to
planning agricultural water, energy, food, and crop area management. Game theory was applied for solving
decision-making problems. The method was applied to construction site selection, and demonstrated that game
theory can be applied for supporting decision in a competitive environment. SWOT analysis can be improved
for planning of sustainable production system in Baluchistan, Pakistan. A fuzzy multi-criteria group
decision-making model was investigated for watershed ecological risk management. A fuzzy-TOPSIS-world open
account (OWA)-based model was developed to identify the impacts of parameters influencing the water
quality failure (WQF) potential. A scenario-based fuzzy interval programming approach was developed for
planning agricultural water, energy, food, and crop area management. Game theory was applied for solving
decision making problems. The method was applied to construction site selection, and demonstrated that game
theory can be applied for supporting decision in a competitive environment. SWOT analysis can be improved
by combining it with MCDM. The Analytic Hierarchy Process (AHP) and the Analytical Network Process
(ANP) analysis have been combined with SWOT analysis. Multiple criteria group decision making applied for
prioritizing SWOT factors.

Despite numerous studies on sustainable water management by researchers and research on sustainability principles, sustainable agricultural water management at the local level and scale has received less attention. Studies by the Organization for Economic Co-operation and Development (OECD) on water sustainability indicators show that analysis at the local level and scale is necessary to demonstrate the effectiveness of the principles of water sustainability.

The analysis of large-scale water resource systems involving multiple components, resources, stakeholders, reservoirs, small irrigation reservoirs, and water transfer schemes is a complex process. This work develops and applies a conceptual framework for sustainable agricultural water use and supply by applying regional management alternatives at multiple spatial scales. The framework is applied to a large scale water resources
system considering social, economic and environmental factors. The framework applies conceptual and analytical methods to sustainable agricultural water management relying on strategic planning and regional multi-criteria decision-making. Previous works have evaluated the sustainability of water resources from different perspectives and methods. This study is novel in its introduction of a framework that measures the sustainability of large-scale agricultural water systems relying on regional management plans.

Method
This section presents the conceptual framework for agricultural water demand and supply management and explains how to apply the conceptual framework for developing regional management alternatives (see Fig. 1). It is seen in Fig. 1 that the conceptual framework consists of two steps, namely, strategic planning and determining the regional priorities, which are explained below. Previous studies have established that entrenched challenges to water resources planning and management are common. Effective implementation of integrated water policies is not common, and has led to a policy implementation gap that leads to incapacity in translating policy into action. This work contributes to closing that gap.

Strategic planning. The main purpose of strategic planning is to identify and analyze internal factors (strengths and weaknesses), external factors (opportunities and threats), and to formulate management alternatives for sustainable development of agricultural water management. The strategic planning stage considers agricultural water use and sources, social, environmental, and economic issues. The evaluation of the internal and external factors and determining the strengths, weaknesses, opportunities, and threats, and the current status of water resources leads to the formulation of sustainable agricultural water management plans, which is the basis for determining the regional priorities in the form of regional management alternatives.

Determining regional priorities based on multi-criteria decision models. Spatial multi-criteria decision making analysis integrates spatial and non-spatial data and incorporates them in the decision-making process. This is accomplished by defining the relationship between input and output maps where by the spatial data and the priorities of the decision makers are accounted for and analyzed according to the rules of decision making.
making. The selected management alternatives defined in the first stage are formulated as a set of regional management alternatives for sustainable development of agricultural water management. Notice therefore that the output of the first stage is a set of management alternatives for sustainable development of agricultural water management, which constitutes the basis for defining regional management alternatives in the second stage. The management alternatives can be structural, non-structural, or a combination of both, which are addressed in terms of water demand and supply management.

Multi-criteria analysis of regional management alternatives for agricultural water demand and supply. This work implements multi-criteria decision making models to prioritize the irrigation management zones in terms of regional management alternatives for agricultural water demand and supply management. The proposed model implemented to prioritize the irrigation management zones is a combination of hierarchical analysis and the TOPSIS in a fuzzy environment.

Study area
The study area is the Sefidroud irrigation and drainage network, Iran, with an area of 284,000 hectares (Fig. 2). The irrigation network is divided into three irrigation management zones, namely, the Markazi, Fumanat, and Shargh irrigation zones, which are divided into 17 irrigation units, 10 of which have modern irrigation and 7 have traditional irrigation system. There are about 300,000 water users in the Sefidroud irrigation and drainage network and the main crop of the irrigation network is rice. About 94% of the total cultivated agricultural land is dedicated to rice fields. The main source of water supply for the Sefidroud irrigation and drainage network is Sefidroud Dam. There are other sources of water for the Sefidroud irrigation and drainage network, such as local rivers, farm wastewater, small irrigation reservoirs, and groundwater.

The Sefidroud irrigation network covers parts of three rivers basins in Iran, and is located in the downstream area of Sefidroud river basin. The Sefidroud basin covers eight provinces of Iran where there are regional conflicts concerning the management of the Sefidroud irrigation network.

Results and application of the approach
This section describes the following topics:
• Analysis and evaluation of agricultural water use and resources in the study area.
• Study and analysis of internal factors (strengths and weaknesses) and external factors (opportunities and threats) related to agricultural water management in the study area.
• Determining the regional management alternatives of agricultural water demand and supply management.
• Multi-criteria analysis of the regional management alternatives of agricultural water demand and supply management.

Analysis and evaluation of agricultural water use. The type of available water resources (Sefidroud network, local rivers, drainage, small irrigation reservoirs and groundwater resources), the crop pattern and quality of soil and water sources vary throughout the study area. Therefore, a database of water-use statistics was prepared to estimate the water use by agricultural lands within the Sefidroud irrigation and drainage network. The water use in the agricultural lands is a function of various factors such as the type of water resources, the method of water conveyance and distribution, the irrigation method, the type of crop products, climatic conditions, soil type, management practice, and others. Therefore, estimating the amount of water use in the agricultural areas in the study area is beset by complexity (Fig. 3).

The inputs to the agricultural water use model are (a) the cultivated area and crop pattern of irrigated lands, (b) the crop water requirements, (c) the irrigation efficiencies and (d) the surface and ground water withdrawal data. The agricultural water use analytical model calculates water use in each irrigation unit by comparing the water requirements of the crop pattern with the water withdrawals of surface water and groundwater. The outputs from this model are actual water use, the contributions of surface and groundwater to water use and the volumes of return flow.

The details of agricultural water use from different water sources (i.e., the Sefidroud dam and its related channels, local rivers, farm wastewater, small irrigation reservoirs, and groundwater) within the irrigated units of the Sefidroud irrigation network are depicted in Fig. 4 and listed in Table 1 for three irrigation management zones. It can be seen in Table 1 that the cultivated area of paddy fields in the Sefidroud irrigation and drainage network has been estimated at about 179,181 hectares. The total annual water use of cultivated area in Sefidroud irrigation and drainage network is about 1.8 billion cubic meters, of which about 1707 million cubic meters (95%) are surface water and 90 million cubic meters (5%) are groundwater. Of the total volume of surface water use about 1.4 billion cubic meters are from the Sefidroud dam and related canals, 260 million cubic meters from local rivers and farm wastewater, and about 47 million cubic meters from small irrigation reservoirs. The average volume of water use in the 191,141 hectares of irrigated lands of the Sefidroud irrigation and drainage network equals 9404 cubic meters per hectare.

Analysis of internal and external factors pertinent to agricultural water management. SWOT analysis was introduced as a tool for complex water resources management (Thaler et al. 2020). This study separates internal and external factors by the geographical boundary of the irrigation network. Thus, the factors
Figure 4. Detailed description of agricultural water use from different water sources in the (a) Markazi, (b) Shargh, (c) Fumanat irrigation management zone.
Figure 4. (continued)

Table 1. Agricultural water use in the irrigation management zones of the Sefidroud irrigation network.

| No | Sefidroud irrigation zones | Irrigated area (ha) | Water supply resources | Water volume ($10^6$ m$^3$) |
|----|---------------------------|---------------------|-----------------------|-----------------------------|
| 1  | Shargh irrigation zone    | 59,797              | Sefidroud irrigation network | 426 |
|    |                           |                     | Local rivers         | 65            |
|    |                           |                     | Small reservoirs      | 24            |
|    |                           |                     | Total surface water use | 515       |
|    |                           |                     | Groundwater use       | 6             |
|    |                           |                     | Total water use       | 521       |
| 2  | Fumanat irrigation zone   | 51,815              | Sefidroud irrigation network | 293 |
|    |                           |                     | Local rivers         | 121          |
|    |                           |                     | Small reservoirs      | 11            |
|    |                           |                     | Total surface water use | 425       |
|    |                           |                     | Groundwater use       | 53            |
|    |                           |                     | Total water use       | 478       |
| 3  | Markazi irrigation zone   | 79,529              | Sefidroud irrigation network | 681 |
|    |                           |                     | Local rivers         | 74            |
|    |                           |                     | Small reservoirs      | 12            |
|    |                           |                     | Total surface water use | 768       |
|    |                           |                     | Groundwater use       | 31            |
|    |                           |                     | Total water use       | 798       |
|    | Sefidroud irrigation network | 191,141            | Sefidroud irrigation network | 1400 |
|    |                           |                     | Local rivers         | 260          |
|    |                           |                     | Small reservoirs      | 47            |
|    |                           |                     | Total surface water use | 1707     |
|    |                           |                     | Groundwater use       | 90            |
|    |                           |                     | Total water use       | 1797     |
were defined according to the management alternatives for agricultural water demand and supply management, the irrigation network system (see Table 3).

Determining the management alternatives for agricultural water demand and supply management. The management alternatives to improve the agricultural water demand and supply management in the Sefidroud irrigation network in 10 irrigation units of the study area were determined to be: (1) Development/Rehabilitation of Sefidroud irrigation network; (2) Improve the management of operation and maintenance of the Sefidroud irrigation network; (3) Wastewater management, and (4) Inter-basin water transfer within the Sefidroud irrigation network system (see Table 3).

The spatial distribution of the management alternatives within the Sefidroud irrigation and drainage network were defined according to the management alternatives for agricultural water demand and supply management, and are shown in Figs. 5, 6, 7 and 8.

Under current conditions the management alternative of development/rehabilitation of the Sefidroud irrigation network’s infrastructure has not been fully implemented. Accordingly, completion and implementation of the main irrigation and drainage network in about 90,000 hectares represents one of the most important priorities in the Sefidroud irrigation network. Carrying out this management alternative would raise the irrigation efficiencies of the Sefidroud irrigation network. Furthermore, in spite of the implementation of the main irrigation and drainage network in 10 irrigation units of the Sefidroud irrigation network, the rehabilitation of the irrigation network in 102,000 hectares is imperative to achieve operational effectiveness.
### Executive policy

| Demand management | Management alternatives |
|-------------------|-------------------------|
| (1) Development/Rehabilitation/Renewing of the Sefidroud Irrigation Network | (1–1) Development and Implementation of the Main Irrigation and Drainage Network in the 7 Remaining Irrigation Units of the Sefidroud Irrigation Network |
| | (1–2) Rehabilitation/Renovation of the Sefidroud Irrigation Network in Under-Operation Irrigation Zones (10 Irrigation Units) |
| | (1–3) Development of On-Farm Irrigation and Drainage Network in the Remaining Areas of the Sefidroud Irrigation Network |
| | (1–4) Equipping and Renovating Paddy Lands in the Remaining Lands of Sefidroud Irrigation Network |
| | (1–5) Mechanization of Paddy Lands |
| (2) Improve the Management of Operation and Maintenance of the Sefidroud Irrigation Network | (2–1) Strengthening the Irrigation Management Institutions of the Sefidroud Irrigation Network with Public Participation |
| | (2–2) Establishment of a Water User Association to Promote Stakeholders Participation in the form of Training, Holding Workshops and Upgrading the Capacities of Irrigation Management Institutions within the Sefidroud Irrigation Network |
| | (2–3) Supervision of Sefidroud Irrigation Network Operation by Consultant Engineers and Providing Documentation for the Irrigation Management Institutions |
| | (2–4) Establishment of Agricultural Water Use Monitoring System in the Sefidroud Irrigation Network |
| Supply management | (3) Wastewater Management |
| (4) Inter-Basin Water Transfer within the Sefidroud Irrigation Network | (4–1) Development and Rehabilitation of small reservoirs in the Sefidroud Irrigation Network |
| | (4–2) Inter-Basin water Transfer within the Sefidroud Irrigation Network through the Construction of Diversion and Rubber Dams in the Downstream of Rivers and Drains |

**Table 3.** Agricultural water demand and supply management alternatives.

**Figure 5.** Spatial distribution of development and rehabilitation lands of the Sefidroud irrigation and drainage network. (Figure created in ArcGIS 10.4 ESRI, [http://www.esri.com](http://www.esri.com)).
The spatial distribution of small irrigation reservoirs is depicted in Fig. 6. It is seen in Fig. 6 that the total number of small irrigation reservoirs in the study area for agricultural water supply is equal to 527, and the total area of the small irrigation reservoirs is 4935 hectares. The total volume of stored water in small irrigation reservoirs is estimated at 197 million cubic meters under the rehabilitation and improvement conditions.

Multi-criteria analysis of agricultural water demand and supply management. A fuzzy multi-criteria decision model was implemented to evaluate the agricultural water demand and supply management alternatives. The prioritization of the regional management alternatives in the Sefidroud irrigation and drainage network, which includes the Markazi, Fumanat, and Shargh irrigation zones, is accomplished with hierarchical analysis methods and the TOPSIS decision-making method in a fuzzy environment, which consists of the following stages:

- Determining appropriate criteria for the decision-making process.
- Calculations related to the hierarchical analysis process.
- Evaluating the alternatives using the fuzzy TOPSIS model, and determining the final prioritization of alternatives.

The alternatives and criteria for decision making are determined and a hierarchical structure is formed. The hierarchical structure has a first level consisting of goals to be achieved, the second level consists of the decision criteria, and the third level consists of the management alternatives.

The weights of the criteria are determined by the hierarchical analysis method once the hierarchical structure is defined, which involves constructing a pairwise comparison matrix to determine the weights. The comparison matrix’s values are determined using Saaty’s table, and the weights of the criteria are calculated based on the geometric mean values. The next step applies the fuzzy TOPSIS algorithm to evaluate the management alternatives in each of the irrigation management zones of the Sefidroud irrigation and drainage network. Lastly, the management alternatives are prioritized. The prioritization uses language variables to evaluate the management alternatives. The fuzzy TOPSIS calculates the CC_j indexes of the management alternatives, such that the alternatives’ rank or desirability increases with increasing value of the CC_j index. The CC_j index is a dimensionless metric in the range [0,1] that measures the closeness of a management alternative to an ideal management alternative or solution.
Identifying the effective criteria in the decision-making process. The decision criteria are of central importance for evaluating the agricultural water demand and supply management alternatives. All the factors that are considered influential in the sustainable management of agricultural water must be studied. The decision criteria are studied separately for each of the irrigation management zones of the Sefidroud irrigation and drainage network to enable accurate decisions representing zonal conditions. Recall that three irrigation management zones of Sefidroud irrigation network are considered. The identified criteria are listed in Table 4.

Evaluating the weights of the decision-making criteria and determining the final ranking of the management alternatives. The criteria listed in Table 4 were classified into four categories: C1 social criteria, C2 economic criteria, C3 environmental criteria, and C4 water consumption and resources management criteria. The calculated weights of the criteria are depicted in Fig. 9. The matrix of weighted fuzzy decision making was calculated using the weights of criteria obtained with the AHP method (Table 5). It is seen in Table 5 that the management alternatives A1 through A3 represent the management alternatives in the irrigation management zones, and C1 through C4 denote the decision-making criteria. Table 5 shows that the elements $\tilde{V}_{ij}$ for all values $i$ and $j$, are normalized in the interval [0,1].

The fuzzy positive ideal solution (FPIS, $A^*$) and the fuzzy negative ideal solution (FNIS, $A^-$) are defined as $\tilde{V}_i^* = (1, 1, 1)$ and $\tilde{V}_i^- = (0, 0, 0)$, respectively, for use in the TOPSIS method with respect to the benefit criteria. The values of FPIS and FNIS are defined as $\tilde{V}_i^* = (0, 0, 0)$ and $\tilde{V}_i^- = (1, 1, 1)$, respectively, for the cost criteria.

All the criteria used in this work to rank of the agricultural water management alternatives are benefit criteria. The distance between the alternatives and the positive ($D^*$) and negative ($D^-$) ideals, and the $CC_j$ indices are computed with TOPSIS. The calculation results for the $CC_j$ index are listed in Table 6, where it is seen that alternative A3 (Fumanat irrigation zone) with $CC_j$ index equivalent to 0.151 is selected as a first priority (top rank) as an agricultural water-demand and supply-management regional management alternative. The lowest priority (bottom rank) of alternatives based on the $CC_j$ index is listed in Table 6. The prioritizing of other alternatives based on $CC_j$ values is also shown in Fig. 10.

Figure 7. Sefidroud irrigation and drainage network land area corresponding to equipping and renovating conditions. (Figure created in ArcGIS 10.4 ESRI, http://www.esri.com).
Sensitivity analysis. The end product of the multi-criteria analysis process consists of proposing an alternative or a set of alternatives for implementation. Sensitive numerical inputs that may have a major impact on the final decision (i.e., the ranking of alternatives) must be identified. The purpose of sensitivity analysis is to determine how the proposed alternatives are affected by changes in inputs (i.e., criteria weights). This analysis evaluates the robustness, or lack of it, of the proposed solution. The sensitivity analysis is performed by changing the weights of the decision making criteria. There are seven combinations of the weights, each defining a weighting scenario, which are listed in Table 7. The results of the sensitivity analysis of the model are listed in Table 7 and Fig. 11. The values of the criteria weights, which are determined from multi-criteria analysis, are listed in Table 7 and Fig. 11. The CC_j values corresponding to the six weighing scenarios are listed in Table 7. CC_{23}, for example, represents a scenario in which the weights of the second and third criteria are changed. It can be seen in Table 7 that the sixth scenario, in which the weights of the second and fourth criteria are changed, establishes that alternative A3 (Fumanat irrigation zone) has the largest CC_j value equal to 0.174 compared to its initial value of 0.151. The scenario, in which the weight of the third and fourth criteria are changed, establishes that alternative A1 (Markazi irrigation zone) has the larger CC_j value equal to 0.163 compared to its initial value of 0.145. Also, the second scenario, in which the weight of the first and second criteria are changed, indicates that alternative A2 (Sharqal irrigation zone) has the largest CC_j value equal to 0.152 compared to the initial value of 0.50.

Concluding remarks
This work develops and applies a conceptual framework of strategic planning and multi-criteria decision making for sustainable agricultural water management. Also an analytical model for estimating agricultural water use based on multiple factors was developed. The results of the agricultural water use analysis and the identification of internal and external factors affecting the management of agricultural water resources led to defining regional management alternatives for agricultural water demand and supply.

Decision making involves the use of a method that accounts for uncertainty within the decision-making process. Hence, a model of decision making with regard to the alternatives (the irrigation management zones of the Sefidroud irrigation and drainage network) was developed based on four water resources sustainability criteria: social, economic, environmental, and water use resource management. The presented framework combines the method of analytical hierarchy and the fuzzy TOPSIS, which permits taking into account the effect of the criteria weights in multi-criteria decision making. The study’s results showed that alternative A3 (the Fumanat irrigation zone) was top ranked (first priority) among other irrigation zones as the best regional management alternative. The sensitivity analysis results have demonstrated that in five among seven scenarios the Fumanat
Table 4. Criteria and indicators for evaluating agricultural water demand and supply management alternatives within the Sefidroud irrigation and drainage network.

| Action plans                              | Criteria/index                                      | Calculation                                                                 |
|-------------------------------------------|----------------------------------------------------|-------------------------------------------------------------------------------|
| (1) Development/rehabilitation/renewing of the Sefidroud irrigation network | Development of main irrigation network              | Area covered by main irrigation network / total area of irrigation network     |
|                                           | Development of on-farm irrigation network           | Area covered by on-farm irrigation network / total area of irrigation network |
|                                           | Equipment and renovating of irrigated lands        | Area covered by equipment and renovating irrigation networks / total area of irrigation network |
| Rehabilitation of irrigation network      | Rehabilitation of irrigation units                  | Area of rehabilitated irrigation units / total area of irrigation network     |
| (2) Improve the management of operation and maintenance of the Sefidroud irrigation network | Operation and maintenance                          | Annual cost for operation and maintenance of irrigation network               |
|                                           | Beneficiary participation                          | No. of Beneficiaries under Water User Association / No. Of Beneficiaries under Irrigation Network |
| Water productivity                        | Development of water user association               | Average amount of product per unit area / average amount of water use per hectare |
|                                           | Water productivity (kg/m³)                          | Average product revenue per unit area / average amount of water use per hectare |
| (3) Inter-Basin water transfer within the Sefidroud irrigation network | Water saving                                       | Regulating water from dams / Volume of agricultural regulated water within the study area / The Total Volume of Agricultural Water Use in the Area |
|                                           | Regulating water from small irrigation reservoirs   | Volume of Agricultural Regulated Water from Small Irrigation Reservoir / The Total Volume of Agricultural Water Use in the Area |
| (4) Wastewater management                 | Water quality                                       | Quality of agricultural drains / The amount of pollutants in agricultural wastewater |

Table 5. The weighted fuzzy decision making matrix. A1: Markazi irrigation zone, A2: Shargh irrigation zone, A3: Fumanat irrigation zone. C1: social criteria, C2: economic criteria, C3: environmental criteria, C4: water use and resources management criteria.

|      | C1                             | C2                        | C3                          | C4                          |
|------|-------------------------------|---------------------------|-----------------------------|-----------------------------|
| A1   | (0.100,0.150,0.100)           | (0.038,0.076,0.114)      | (0.280,0.350,0.350)         | (0.042,0.084,0.126)        |
| A2   | (0.050,0.100,0.150)           | (0.076,0.114,0.152)      | (0.070,0.140,0.210)         | (0.126,0.168,0.210)        |
| A3   | (0.200,0.250,0.250)           | (0.114,0.152,0.190)      | (0.140,0.210,0.280)         | (0.000,0.042,0.084)        |

Ideal (+) $V_1^+ = (1,1,1)$ $V_2^+ = (1,1,1)$ $V_3^+ = (1,1,1)$ $V_4^+ = (1,1,1)$
Ideal (-) $V_1^- = (0,0,0)$ $V_2^- = (0,0,0)$ $V_3^- = (0,0,0)$ $V_4^- = (0,0,0)$

Figure 9. The results of the analytical hierarchical process (AHP). C1: social criteria, C2: economic criteria, C3: environmental criteria, C4: water use and resources management criteria.
Table 6. The ranking of alternatives based on the CCj index. A1: Markazi irrigation zone, A2: Shargh irrigation zone, A3: Fumanat irrigation zone.

| Alternatives | $D_i$ | $D_j$ | CCj | Final ranking of alternatives |
|--------------|-------|-------|-----|-------------------------------|
| A1           | 3.442 | 0.586 | 0.145 | 3                            |
| A2           | 3.426 | 0.603 | 0.150 | 2                            |
| A3           | 3.422 | 0.611 | 0.151 | 1                            |

Figure 10. Prioritization of irrigation zones of the Sefidroud Irrigation and Drainage Network in terms of implementation of demand and supply management alternatives. (Figure created in ArcGIS 10.4 ESRI, http://www.esri.com).

Table 7. Sensitivity analysis of the results. A1: Markazi irrigation zone, A2: Shargh irrigation zone, A3: Fumanat irrigation zone. W1: Weight of social criteria. W2: Weight of economic criteria. W3: Weight of environmental criteria. W4: Weight of water use and resources management criteria.

| Scenario | Weights of criteria | CCj index values per alternatives |
|----------|---------------------|----------------------------------|
|          | W1 | W2 | W3 | W4 | A1  | A2  | A3  |
| 1 = Main | 0.25 | 0.19 | 0.21 | 0.35 | 0.145 | 0.150 | 0.151 |
| 2 = CC_{12} | 0.19 | 0.25 | 0.21 | 0.35 | 0.143 | 0.152 | 0.150 |
| 3 = CC_{13} | 0.21 | 0.19 | 0.25 | 0.35 | 0.149 | 0.150 | 0.148 |
| 4 = CC_{14} | 0.35 | 0.19 | 0.21 | 0.25 | 0.150 | 0.149 | 0.169 |
| 5 = CC_{23} | 0.25 | 0.21 | 0.19 | 0.35 | 0.143 | 0.151 | 0.152 |
| 6 = CC_{24} | 0.25 | 0.35 | 0.21 | 0.19 | 0.145 | 0.142 | 0.174 |
| 7 = CC_{34} | 0.25 | 0.19 | 0.35 | 0.21 | 0.163 | 0.136 | 0.164 |
irrigation zone was ranked first with respect to regional management alternatives for agricultural water demand and supply. The framework developed in this work can be applied to other large scale water resources system in which regional differentiation is essential for sustainable water management.

Data availability
All relevant data are included in the paper or its supplementary information.

Received: 1 January 2022; Accepted: 4 May 2022
Published online: 19 May 2022

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Acknowledgements
The authors thank Iran's National Science Foundation (INSF) for its support of this research.

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Credit Author Statement: A.R. First author, Data curation; Investigation; Formal analysis; Resources; Roles/Writing—original draft. O.B.-H., Second Author, Corresponding author, Conceptualization; Funding acquisition; Methodology; Project administration; Supervision; Validation; Visualization; Roles/Writing—original draft. H.A.L., Third author, Validation; Visualization; Writing—review and editing.

Competing interests
The authors declare no competing interests.

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