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Evaluation of River Water Transfer Alternatives with the TODIM Multi-Criteria Decision Making Method

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Abstract
Access to water as the core of sustainable development is essential for the socio-economic development of any region. Water security is challenging, especially in arid and semi-arid regions such as Iran, where changes in the temporal distribution of precipitation contribute to the inherent shortage of water resources. Therefore, it is necessary to choose strategies that can advance this heterogeneous distribution towards balance. One of these strategies consists of inter-basin water transfers. This work presents a methodology for selecting the best alternative for river-water transfer relying on multi-criteria decision making. The method is evaluated in the Khodaafarin irrigation network (Ardabil province, Iran). Environmental, economic, technical, and socio-cultural criteria and related sub-criteria are weighted with Analytical Hierarchy Process (AHP). The multi-criteria decision making method (TODIM) is applied to rank the management alternatives. The results of the AHP model show that the sub-criterion of investment costs with a weight of 0.264 is the most effective criterion for choosing the most suitable water-transfer alternative. Also, the results of the TODIM decision-making method indicate the best-ranked alternative consists of water transfer through an existing earthen canal to a pumping lift station, construction of the pumping station at 0 + 400 km, and water conveyance by a concrete canal, with dominance degree of −13.72. The second-best alternative (i.e. water transfer to the pumping station by gravity pipe, construction of the pumping station, and water conveyance by concrete canal) has a dominance degree of −15.54.

Keywords TODIM multi-criteria decision making method · AHP weighting method · Water transfer · Sustainable water resources management

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1 Introduction

Population growth, increased water consumption in agriculture to produce food, industrial growth, and economic development have increased water demand (see Golfam et al., 2019a; Golfam et al., 2019b). Water-transfer projects are one of the options implemented in different parts of the world to achieve sustainable water resource management.

Extensive use of this option has not been without challenges. Fair distribution of project benefits, preservation of natural ecosystems, protection of social and environmental rights, geological, land-use, and hydrologic impacts arising from inter-basin water transfer are among the issues that must be carefully evaluated before projects move forward (Yevjevich, 2001).

Knapp et al. (2003) examined the effects of water transfers on aquifers and agricultural production in the state of California (USA). The results showed that due to the region's strong agricultural dependence on groundwater the transfer of surface water caused a sharp drop in the groundwater level, and only efficient economic management can reduce some of the adverse consequences. Ghassemin and White (2007) reviewed the characteristics of inter-basin water transfer projects in Australia, the United States, Canada, China and India. Thatte (2007) stated that due to India's population and lack of fresh water the lack of inter-basin water transfer could have serious social and environmental consequences. Karakaya et al. (2014) examined the socio-economic and environmental consequences of inter-basin water transfers as a strategy to achieve sustainable water resources management in Turkey.

It is commonly difficult to choose the most suitable alternative for water transfers and its optimal allocation to maximize benefits to stakeholders and participants and to minimize environmental adverse impacts. To overcome this problem the use of multi-criteria decision-making methods represents a comprehensive and sustainable strategy within the framework of integrated water supply and demand management.

Sadegh et al. (2010) applied a Crips and Fuzzy Shapely Games model to optimal allocate water resources of the inter-basin water transfer from Karoon basin (in southwestern Iran) to Rafsanjan plain (in central Iran). First, the initial allocation of water was optimized according to the standard of equity. Stockholders formed a Crips coalition to increase their benefits and the total net benefit of the water system. This was followed by implementation of the Shipple index to redistribute the benefits generated. The last step formed a fuzzy coalition and based on the level of consumer participation water use was optimized so that the total benefit was shared fairly by water users.

Zhu et al. (2016) reported a financing model to transfer water from Han to the Wei River in China's Shaanxai Province. The complex structure of the model was analyzed with hierarchical decomposition method, and the weight of the evaluation index was obtained with the AHP method. The Delphi method converted experts' financial opinions to an evaluation matrix to calculate the Approaching Degree of the financing model with the Weighted Grey Target Model.

Roozbahani et al. (2020) reported the multi-criteria decision making method Complex Proportional Assessment (COPRAS) applied to integer, grey, and fuzzy environments to evaluate the inter-basin water transfer from the Karoon catchment to the Central Iranian Plateau under eight scenarios to remedy the drinking water shortage. First, the design criteria were determined and weighted according to UNESCO's standards; eight scenarios were ranked with the COPRAS method. The results demonstrated that technical risks, the difficulties of project execution, and the cost of water were the most important criteria. The water transfers from Beheshtabad basin to Isfahan province, and from Khersan basin to Yazd and Kerman provinces were selected as the best alternatives.

Bozorg-Haddad et al. (2020) relied on the GRACE satellite data to develop a method for assessing the relation between water scarcity and conflict in the provinces of Iran in the period (2002–2016). The water transferability index measured the conditions in the provinces concerning inter-basin water transfer with the aim of resolving associated conflicts. Their results indicated the Bushehr region could be one of the provinces exporting water. On the other hand, water transfers in the western provinces of Iran would intensify conflicts due to the severe shortage of water.

Reviews of previous works have shown that water-transfer constitutes is sometimes a suitable option for improving water supply; yet, there are related challenges. The economic justification of water transfers, the technical capacity and infrastructure for their implementation, and the environmental degradation in the exporting and receiving regions are key challenges to the construction of water transfer projects. Multi-criteria decision-making methods can be applied to consider multiple criteria related to the evaluation of water-transfer projects within a systematic framework.

This study applies multi-criteria, decision making, methods to select the best alternative for transferring river water to the Khodaafarin irrigation network (Ardabil Province, Iran). The set of main criteria and sub-criteria and the water-transfer alternatives are determined according to regional conditions. This is followed by application of the Expert Choice 11 model based on the AHP method to calculate the weights of the sub-criteria. Lastly, the water-transfer alternatives are ranked and the best alternative is determined with the TODIM multi-criteria decision making method.

2 Methods and Materials

This section describes the methods used in the present study. The AHP weighting method determines the weight of the criteria and sub-criteria associated with water transfer. The TODIM multi-criteria decision making method is applied to rank the proposed water-transfer alternatives.

2.1 The AHP Weighting Method

Saaty (1980) developed the AHP weighting and ranking method based on the four principles of reciprocity, homogeneity, dependency, and expectations. The AHP model compares criteria for determining their relative superiority from the perspective of experts. The AHP model first establishes the goal level, next defines the criteria level, and, if necessary, the sub-criteria level, and ranks the problem's alternatives. The AHP model includes the following steps:

(a) Creating a problem structure

This step defines the problem's goal, criteria, sub-criteria, and alternatives. Water-transfer projects are commonly complex decision-making issues due to their multiple dimensions and impacts. Therefore, it is necessary to carefully examine the proposed criteria and alternatives before implementing a water-resource plan.

(b) Pairwise comparison of criteria

In this stage the AHP method survey questionnaire is prepared and provided to the experts, who assign a number between one and nine (see Table 1) according to their viewpoints on the criteria comparative performances. This work considered 4 main criteria. Therefore, 4 experts in the fields of economic, environment, social-agriculture, and ecosystems were selected. According to Aczel and Saaty (1983) the best method to weigh each expert's pairwise comparison consists in using the geometric mean of each expert's scores. This work applied the geometric mean to calculate the experts' final score.

Pairwise comparison matrices A of size $m \times m$ are formed for a problem with m alternatives and n criteria. Let A compare the m alternatives with respect to the kth criterion. The matrix A is expressed as follows (Saaty, 1977):

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix} \tag{1}$$

where, a_{ij} = the superiority of alternative i over alternative j, with respect to criterion k. The diagonal of A is equal to 1 because the superiority of any alternative over itself equals 1. There are n comparison matrices, one for each of the n criteria.

(c) Calculate the decision consistency rate of the criteria

The consistency rate of the criteria measures the compatibility of the pairwise comparison between the criteria (Saaty, 1977). The decision consistency rate of each criterion is calculated with the following equations:

$$DCR = \frac{DCI}{DRI} \tag{2}$$

$$DCI = \frac{\lambda_{\max} - m}{m - 1} \tag{3}$$

where, DCR = decision consistency rate; DCI = decision consistency index; DRI = decision random inconsistency; m = dimension of comparison matrix A for the k-th criterion; $\lambda_{\max}$ = maximum eigenvalue (λ) (λ is obtained by solving $|A - \lambda I| = 0$, where I is the identity diagonal matrix). The DRI values for square matrices of size $m \times m$ are given in Table 2.

The decision consistency rate of the criteria is an index that measures the consistency of experts' answers to their evaluations and pairwise comparisons. In the other words, the decision consistency rate helps the decision-makers to understand if there is consistency between pairwise comparisons or not. The comparison of criteria is consistent if the DCR value is less than or equal to 0.1. Otherwise, the pairwise comparison of the criteria must be repeated. The DCI values defined by Saaty are based on the magnitude of the pairwise comparisons matrix. Saaty (1977) argued that the decision consistency rate should less than 0.1.

2.2 TODIM Multi-Criteria Decision Making Method

The word TODIM in Portuguese means interactive and multiple attribute decision making, first introduced by Gomes and Lima (1992a, b). The TODIM decision-making method is a discrete method based on prospect theory (Kahneman and Tversky, 1979). The basis of prospect theory is the decision between several alternatives with different prospects, each of which is associated with risk. The shape of the value function in the TODIM method is the same as the gain/loss function in prospect theory.

This method is based on the global multi-attribute value function that aggregates all the values of gains and losses for all criteria. The global multi-attribute value function depends on the difference between the values of the two alternatives relative to a reference criterion, and this pairwise comparison eliminates the inconsistency resulting from these comparisons. The following are the steps of the TODIM method:

(a) Formation of the decision making matrix

Assuming m alternatives and n criteria the decision matrix is formed based on the performance of alternative i according to criterion j as follows.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, (i = 1, 2, \cdots, m; c = 1, 2, \cdots, n) \tag{4}$$

where, x_{ij} = the performance of alternative i according to the criterion j.

(b) Normalization of the decision-making matrix

The positive and negative criteria are determined and normalized based on Eqs. (5) and (6), respectively.

$$R_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{5}$$

Table 1 The superiority criteria expressed numerically

The type of preference	Value
Same preference	1
Medium preference	3
Strong preference	5
Very strong preference	7
Infinite preference	9
Intermediate values	2, 4, 6, 8

Table 2 The DRI index value

m	1	2	3	4	5	6	7	8	9
DRI	0	0	0.52	0.9	1.12	1.24	1.32	1.41	1.45

$$R_{ij} = \frac{1/x_{ij}}{\sum_{i=1}^{n} 1/x_{ij}} \tag{6}$$

where, R_{ij} = normalized elements of decision-making matrix.

(c) Determining the relative weight of the criteria

The weights obtained by the AHP method are divided by the reference criterion (i.e. the criterion with the largest weight), and the relative weights of the criteria are obtained:

$$w_{jr} = w_j / w_r \tag{7}$$

where, w_{jr} = the relative weight of the criterion; w_j = the weight of the criterion j; w_r = the weight of the reference criterion.

(d) Determining the dominance degree of alternative i over alternative k

The dominance degree of each alternative relative to other alternatives is calculated according the following equation:

$$\phi_j(A_i, A_k) = \begin{cases} \sqrt{\dfrac{w_{cr}\left(P_{ij} - P_{kj}\right)}{\sum_{j=1}^{m} w_{cr}}} & \mathit{if}\ \left(P_{ij} - P_{kj}\right) > 0 \\ 0 & \mathit{if}\ \left(P_{ij} - P_{kj}\right) = 0 \\ \dfrac{-1}{\theta}\sqrt{\dfrac{\left(\sum_{j=1}^{m} w_{cr}\right)\left(P_{ij} - P_{kj}\right)}{w_{cr}}} & \mathit{if}\ \left(P_{ij} - P_{kj}\right) < 0 \end{cases} \tag{8}$$

where, $(P_{ij} - P_{kj}) > 0$ and $(P_{ij} - P_{kj}) < 0$ = gain or loss of alternative i relative to criterion j, respectively. Also, θ = the attenuation factor of the losses whose value is determined by the decision makers. Its value is set equal to 1 in this work.

(e) Calculate the final dominance degree of alternative i over alternative k

The final dominance degree of alternative i over alternative k is calculated with the following equation:

$$\delta(A_i, A_k) = \sum_{j=1}^{m} \phi_j(A_i, A_k) \tag{9}$$

where, $\delta(A_i, A_k)$ = the final dominance degree of alternative i over alternative k.

(f) Determine the overall value of each alternative

The overall value of each alternative (ξ_i) is determined with Eq. (10):

$$\xi_i = \frac{\sum_{j=1}^{n}\delta(A_i, A_k) - \min\sum_{j=1}^{n}\delta(A_i, A_k)}{\max\sum_{j=1}^{n}\delta(A_i, A_k) - \min\sum_{j=1}^{n}\delta(A_i, A_k)} \tag{10}$$

(g) Ranking alternatives

The ranking of alternatives is determined by the overall value of each alternative. That is, the larger the value ξ_i of an alternative, the more desirable the alternative is.

3 Case Study, Criteria and Alternatives under Review

3.1 The Study Region

This paper's study region is located south of the Aras River and west of Parsabad city in Ardabil province, Iran. Figure 1 depicts the study region. The two main locations of the water-transfer project are an intake location or diversion point on the Aras River, and a discharge location on the conveyance canal 'A'. The coordinates of the intake location are coordinates X = 728,046 and Y = 4,382,116, and those of discharge location are X = 728,046 and Y = 4,382,116, respectively.

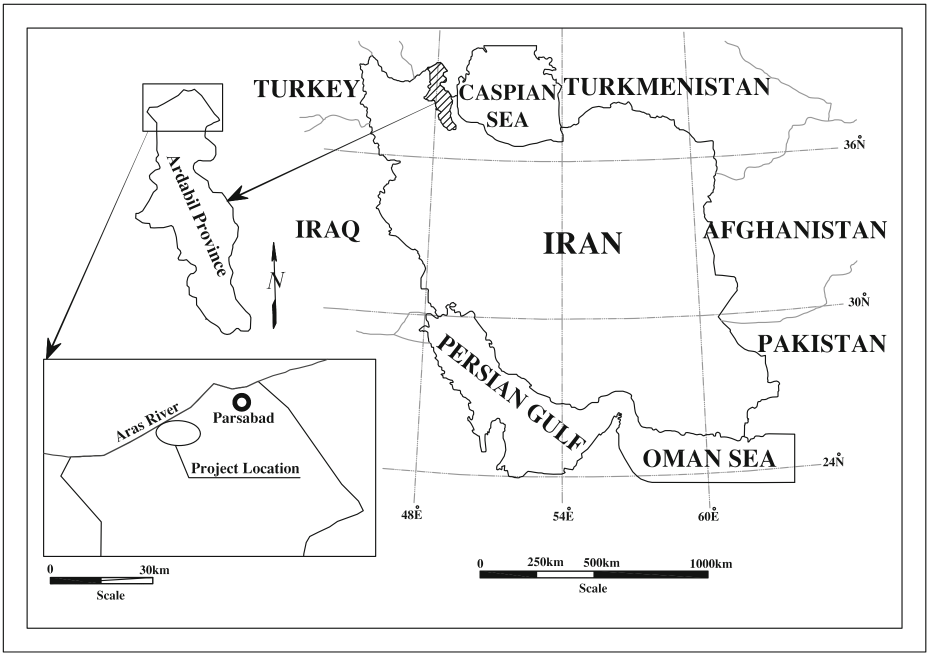

Fig. 1 National Iran and provincial (Ardabil) map (with Parsabad City and Aras River)

The water-transfer project will provide water to development areas within the Khodaafarin network. Water intake from the Aras Rivers is, followed by water conveyance through 9 km to the Moghan 'A' canal. The initial intent was to divert water from the Aras River and convey it 9 km in the canal 'A' by gravity. Surveying revealed that gravity flow cannot occur as initially envisioned, and that hydraulic lift was required to provide the necessary hydraulic head for water conveyance. Several water-transfer alternatives have been proposed that are herein analyzed.

3.2 Determining and Examining Possible Alternatives

The first step in the water-transfer project is evaluating the water intake and transfer condition. For this purpose mapped cross sections of the channel route were measured. The water level of the Aras River equaled 76.10 m in March 2017. Calculations of the water level profile between stations 0 + 000 and 2 + 800 km of an existing earth canal were carried out. The first and second columns of Table 3 lists the codes assigned to the stations of the existing earthen canal in the HEC RAS hydraulic model. The third and fourth columns of Table 3 lists the results of the water surface elevation calculations.

The results of Table 3 establish that it is not possible to transfer water by gravity from the Aras River to the discharge location through the existing earth canal. Therefore, the transfer of 5 m^3/s of water from the Aras River requires a rise of hydraulic head through the construction of a pumping station, whose location must be determined. The results of field visits and surveys indicate possible locations for the pumping station at 0 + 400, 0 + 900, or 2 + 800 km. It is known, however, that water transfer from Aras River to the pumping site would require deepening the existing canal or constructing a pipeline at great depth. This means the pumping station must be as close as possible to the river intake location. Therefore, 0 + 400 km is the most

Table 3 Results of water level simulation in the existing canal up to station 2 + 800 km

Stations (km)	Code number	Q (m^3/s)	Water surface elevation (m)
0 + 000	17	5	76.16
0 + 100	16	5	76.16
0 + 200	15	5	76.16
0 + 350	14	5	76.15
0 + 400	13	5	76.15
0 + 600	12	5	76.15
0 + 900	11	5	76.15
1 + 150	10	5	76.15
1 + 300	9	5	76.15
1 + 400	8	5	76.15
1 + 600	7	5	76.15
1 + 750	6	5	76.15
1 + 850	5.5	5	76.15
1 + 950	5	5	76.14
2 + 150	4	5	76.08
2 + 300	3	5	76.02
2 + 550	2	5	75.97
2 + 800	1	5	75.97

Table 4 Weights of the main criteria and environmental, economic, technical, socio-cultural sub-criteria

Weight of main criterion				
Environmental	Economic	Technical	Socio-Cultural	
0.302	0.435	0.147	0.116	
Consistency ratio = 0.07				
Weight of environmental sub-criteria				
Effects on humans	Effects on plant species	Effects on soil	Effects on water resources	Effects on natural ecosystems
0.427	0.099	0.085	0.151	0.238
Consistency ratio = 0.03				
Weight of economic sub-criteria				
Investment cost	Operation and maintenance cost		Energy cost for water transfer	
0.605	0.104		0.291	
Consistency ratio = 0.1				
Weight of technical sub-criteria				
Facilities and equipment	Feasibility		Ease of operation	
0.517	0.124		0.359	
Consistency ratio = 0.1				
Weight of socio-cultural sub-criteria				
General acceptance		Farmers' opposition		
0.667		0.333		
Consistency ratio = 0.0				

suitable location for constructing the pumping station. Based on these considerations the water-transfer alternatives are as follows:

– The first alternative:

Transfer of Aras River water to the pumping station by an existing earthen canal, construction of the pumping station at 0 + 400 km, and transfer of water by concrete canal.

– The second alternative:

Transfer of Aras River water to the pumping station by gravity pipe, construction of the pumping station at 0 + 400 km, and transfer of water by concrete canal.

– The third alternative:

Transfer of Aras River water to the pumping station by gravity pipe, construction of the pumping station at 0 + 400 km, and transfer of water by pipe

– The fourth alternative:

Transfer of Aras River water to the pumping station by an existing earthen canal, construction of the pumping station at 0 + 400 km, and transfer of water by pipe.

This paper's selection of the best alternative considered environmental, economic, technical, and socio-cultural criteria. Several sub-criteria were defined for allocating appropriate scores by decision makers to each criterion. The environmental criterion has sub-criteria concerning the effects on humans, the effects on plant species, the effects on soil, the effect on water resources, the effect on natural ecosystems. The economic criterion has sub-criteria concerning investment costs, operating and maintenance costs, and energy consumption costs of water transfer. The technical criterion has sub-criteria concerning the desired facilities and equipment, feasibility, ease of operation. The socio-cultural criterion has sub-criteria concerning public acceptance, and farmers' opposition.

Table 5 The final weights of the sub-criteria

Main criterion	Sub-criterion	Final weight
Environmental	Effects on humans	0.129
	Effects on plant species	0.030
	Effects on soil	0.026
	Effects on water resources	0.046
	Effects on natural ecosystems	0.072
Economic	Investment cost	0.264
	Operation and maintenance cost	0.046
	Energy cost for water transfer	0.127
Technical	Facilities and equipment	0.076
	Feasibility	0.019
	Ease of operation	0.053
Socio-cultural	General acceptance	0.078
	Farmers' opposition	0.039

Sum weights = 1

Table 6 Decision matrix

Alternatives	Criteria												
	C_1 (benefit)	C_2 (benefit)	C_3 (benefit)	C_4 (benefit)	C_5 (benefit)	C_6 (cost)	C_7 (cost)	C_8 (cost)	C_9 (benefit)	C_{10} (benefit)	C_{11} (benefit)	C_{12} (benefit)	C_{13} (benefit)
A_1	80	60	66	80	80	100	90	100	100	100	90	80	75
A_2	60	80	77	70	70	80	80	90	50	86	79	90	85
A_3	70	60	60	60	50	30	40	30	30	40	20	40	60
A_4	70	60	65	75	68	60	40	50	40	60	70	70	90

A_1 = Transfer of Aras River water to the pumping station by the existing earthen canal, construction of the pumping station (at 0 + 400 km) and transfer of water by concrete canal

A_2 = Transfer of Aras River water to the pumping station site by gravity pipe, construction of the pumping station and transfer of water by concrete canal

A_3 = Transfer of Aras River water to the pumping station site by gravity pipe, construction of the pumping station and transfer of water by pipe

A_4 = Transfer of Aras River water to the pumping station site by the existing earthen canal, construction of the pumping station, and transfer of water by pipe

Table 7 Normalized decision matrix

Alternatives	Criteria												
	C_1 (benefit)	C_2 (benefit)	C_3 (benefit)	C_4 (benefit)	C_5 (benefit)	C_6 (cost)	C_7 (cost)	C_8 (cost)	C_9 (benefit)	C_{10} (benefit)	C_{11} (benefit)	C_{12} (benefit)	C_{13} (benefit)
A_1	0.28	0.23	0.24	0.28	0.29	0.13	0.15	0.13	0.45	0.34	0.34	0.28	0.24
A_2	0.21	0.31	0.28	0.24	0.26	0.17	0.17	0.14	0.22	0.30	0.30	0.32	0.27
A_3	0.25	0.23	0.22	0.21	0.18	0.45	0.34	0.45	0.13	0.13	0.07	0.14	0.19
A_4	0.25	0.23	0.24	0.28	0.25	0.22	0.34	0.27	0.18	0.21	0.27	0.25	0.29

4 Results

4.1 Weight of Criteria and Sub-Criteria

Implementing the Expert Choice 11 software produced the weights of the criteria and sub-criteria. Table 4 lists the weights of the main criteria. According to Table 4 the economic criterion has the highest weight among the main criteria. The environmental criterion with a weight of 0.302 is the second most important, which is due to the occurrence of adverse environmental impacts related to project construction.

The weights of the sub-criteria were obtained with the Expert Choice 11 software. The weights of the environmental sub-criteria are listed in Table 4. Among the environmental sub-criteria the effects on humans, with a weight of 0.427, is the most important one. All economic sub-criteria are negative (i.e., they are costs). The weights of the economic sub-criteria are listed in Table 4, where it is seen the sub-criterion of investment costs with a weight of 0.605 is the most important economic factor in this instance. The weights of the technical and socio-cultural sub-criteria are presented in Table 4. After calculating the weights of the main criteria and sub-criteria the weight of each sub-criterion was multiplied by the weight of its main criterion to obtain the final weights of the sub-criteria listed in Table 5. Among the 13 sub-criteria for the present project the sub-criteria of investment costs, the effect on humans, and the energy input costs for water transfer with weights of 0.264, 0.129 and 0.127, respectively, are the most important sub-criteria according to the experts' views.

4.2 Ranking and Selecting the Best Alternative

The decision matrix is shown in Table 6. Based on the profit and cost of the criteria the normalized decision matrix was obtained and is listed in Table 7. The relative weights of the sub-criteria were obtained and are listed in Table 8. The relative dominance of alternative *i* with respect to alternative *j,* and the final dominance of each alternative over the other alternatives is listed in the last column of Table 9. The final dominance degree of each alternative is shown in Table 10. Figure 2 depicts the ranking of alternatives based on the best value of each alternative (ζ_i). It is seen in Fig. 2 that the greater the final dominance degree of each alternative, the greater its total value and the higher its rank. Therefore, the first alternative, namely River Aras water transfer to the pumping station location by an existing

Table 8 Relative weights of the sub-criteria

Sub-criteria	Relative weight
Effects on humans	0.49
Effects on plant species	0.11
Effects on soil	0.09
Effects on water resources	0.17
Effects on natural ecosystems	0.27
Investment cost	1.00
Operation and maintenance cost	0.17
Energy cost for water transfer	0.48
Facilities and equipment	0.28
Feasibility	0.06
Ease of operation	0.20
General acceptance	0.29
Farmers' opposition	0.14

Table 9 The dominance degree of each alternative over other alternatives according to each criterion

Alternatives	The dominance degree of A_1 over other alternatives													
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	$\delta(A_1, A_k)$
A_2	0.096	−1.60	−1.26	0.04	0.052	−0.362	−0.645	−0.343	0.131	0.029	0.047	−0.679	−0.913	−5.416
A_3	0.067	0	0.024	0.056	0.089	−1.105	−2.042	−1.573	0.155	0.061	0.119	0.105	0.043	−3.9984
A_4	0.067	0	0.009	0.028	0.056	−0.591	−2.042	−1.030	0.144	0.050	0.063	0.052	−1.119	−4.3091
Alternatives	The dominance degree of A_2 over other alternatives													
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	$\delta(A_2, A_k)$
A_1	−0.744	0.048	0.032	−0.877	−0.720	0.095	0.029	0.043	−1.729	−1.638	−0.897	0.052	0.035	−6.2708
A_3	−0.526	0.048	0.040	0.040	0.073	−1.044	−1.937	−1.535	0.083	0.054	0.109	0.117	0.055	−4.4224
A_4	−0.526	0.048	0.033	−0.620	0.023	−0.467	−1.937	−0.971	0.058	0.040	0.042	0.074	0.646	−4.8470
Alternatives	The dominance degree of A_3 over other alternatives													
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	$\delta(A_3, A_k)$
A_1	−0.526	0	−0.933	−1.240	−1.248	0.291	0.092	0.199	−2.046	−3.392	−2.263	−1.358	−1.119	−13.5457
A_2	0.067	−1.604	−1.572	−0.877	−1.019	0.275	0.087	0.194	−1.093	−2.970	−2.077	−1.519	−1.444	−13.5531
A_4	0	0	−0.852	−1.074	−0.966	0.246	0	0.150	−0.773	−1.958	−1.912	−1.176	−1.582	−9.9012
Alternatives	The dominance degree of A_4 over other alternatives													
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	$\delta(A_4, A_k)$
A_1	−0.526	0	−0.381	−0.620	−0.789	0.155	0.0992	0.130	−1.894	−2.770	−1.209	−0.679	0.043	−8.4489
A_2	0.067	−1.604	−1.320	0.028	−0.322	0.123	0.087	0.122	−0.773	−2.233	−0.811	−0.960	0.025	−7.5711
A_3	0	0	0.021	0.049	0.069	−0.934	0	−1.189	0.058	0.035	0.100	0.091	0.061	−1.6362

Table 10 The final dominance degree of each alternative

	A_1	A_2	A_3	A_4	Final dominance degree
A_1	0	−5.4165	−3.9984	−4.3091	−13.7240
A_2	−6.2708	0	−4.4224	−4.8470	−15.5402
A_3	−13.5457	−13.5531	0	−9.9012	−37
A_4	−8.4489	−7.5711	−1.6362	0	−17.6562

earthen canal, construction of the pumping station (at 0 + 400 km), and water transfer by concrete canal has the highest final dominance degree and was the top-ranked alternative.

The second-ranked alternative means River Aras water to the pumping station location by gravity pipe, construction of pumping station at 0 + 400 km, and transfer of water by concrete canal with final dominance degree of −15.54 and total value of 0.992 (this is called the second alternative in this work). River Aras water transfer to the pumping station location by existing earthen canal, construction of pumping station, and transfer by pipe was the third-ranked alternative (this is called the fourth alternative in this work) with final dominance degree equal to −17.6562. The third alternative (i.e. River Aras water transfer to the pumping station location, and transfer by gravity pipe) was the lowest-ranked alternative with a final dominance degree equal to −37, and a total value of zero compared to the other alternatives.

5 Concluding Remarks

Water transfer projects are challenging measures to supply water due to the geographical factors, and socio-economic costs that are incurred during and after construction. Selecting the best water-transfer alternative among several alternatives creates a difficult multi-attribute decision making processes in which conflicting opinions among experts may arise. The best approach to resolve these selection problems lies with multi-criteria decision making methods.

Multi-criteria decision making was applied in this study to select the best water-transfer alternative in the Khodaafarin irrigation network, Iran. Specifically, this work relied on TODIM multi-criteria decision making which considers the main criteria and sub-criteria to select the best alternative for water transfer based on conditions prevailing in the study area.

The Expert Choice 11 model based on the AHP method was applied to calculate the weights of the main criteria and sub-criteria and their consistency rates. The calculated weights were input to the TODIM model to calculate the final ranking of the alternatives. The results of

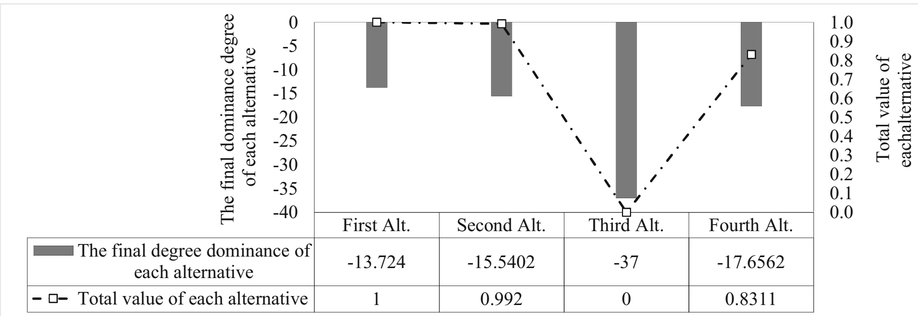

Fig. 2 Final ranking of alternatives

the TODIM multi-criteria decision-making method indicate the best alternative among four alternatives was transferring water through an existing earthen canal to a pumping lift station, construction of the pumping station at 0 + 400 km, and water conveyance by a concrete canal. The advantages of this alternative compared the other alternatives were as follows:

The costs would be greatly reduced by using the existing earthen canal and improving the floor level up to 0 + 400 km. Equipment is for blocking the canal and collection garbage, only. Also, it is possible to dredge the canal every year at the proper time. Therefore, service and maintenance are relatively easy and possible with local resources.

In general, water transferring through open concrete canal requires less pumping head than water transferring through pipe. The operating cost of open concrete canal depends on the geography of the case study. In this case there is a balance between fill and excavation, leading to cost savings.

The alternatives with gravity pipe are challenging and expensive due to the high groundwater level because water conveyance with gravity pipe must be done at great depth. On the other hand, corrosion of metal pipes is severe. It is difficult to prevent sediment from entering pipes, and filtration equipment must be provided at pipe's intake to prevent intrusion of suspended matter.

This paper presents the first application of the TODIM multi-criteria decision-making method ranking alternatives for water transfer. TODIM method is based on the dominance degree of each alternative over the other alternatives. Thus, alternatives are compared pairwise and the best alternative is selected after their thorough evaluation.

6 General Recommendations

(1) Water resources development projects, especially water transferring projects, are challenging because of the need to construct infrastructure for water transferring and usually complex conditions in the water exporting and importing regions. Therefore, profound knowledge of the project area and the options for water transferring is the essential to choose the best water-transfer alternative.

(2) The water transfer alternatives are identified, followed by the selection of the evaluation criteria with which to to select the best alternative Experts knowledgeable to the evaluation criterion must be involved in the selection process.

(3) The timing of decision-making is important. A variety of fuzzy or gray concepts should be used for accounting of future uncertainties when policy making would affect conditions in the long term.

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