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Economics Prioritization of the Allocation of Chahnimeh Reservoir Water Using Fuzzy Multiple-Criteria Decision-Making (FMCDM) Models

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Abstract

The main objective of the present study was to prioritize the allocation of water resources of *Chahnimeh* reservoirs from economic, social, and environmental perspectives in 2015-2016 season using fuzzy analytic hierarchy process (FAHP) and fuzzy technique for order preference by similarity of an ideal solution (FTOPSIS) as the branches of fuzzy multiple-criteria decision-making (MCDM) models. Data were collected from the experts and officials of the relevant organizations by a questionnaire. Nine parameters were used for prioritization and modeling. Results revealed that in FAHP from economic and social perspectives, agriculture sector had the highest weights of 0.4 and 0.269, respectively. However, the priority to enjoy the water of three Hāmūn lagoons was granted to environmental sector in environment perspective. FTOPSIS results confirmed the results of FAHP.

Keywords: Prioritization Economics, Water Resources, Multiple-Criteria Decision-Making, Chahnimeh, Sistan.

JEL Classification: Q_{25}, O_{13}.

1. Introduction

Water has been traditionally a driving force of development, especially agricultural development, in the world. Although the Earth possesses a plenty of water resources, 97% of them are saline and just a limited number of them are available for people to use. As well, over

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76.1% of water is in the unavailable forms of crystals and frozen rivers, and the remaining lay down in the depths of the Earth. Given the fact that most countries have been long suffering from severe crisis of water resource limitations and other countries are added to them due to population growth and economical and social development, it can be said that water system problems will be undoubtedly multiplied in future and water will gain a growing importance. The climatic change and the increase in mean temperature of the Earth will augment evaporation, boosting the demand for water. The Middle East is no exception so that new challenges of water resources will be confronted due to more frequent droughts, growing demand for water, and water deficit. Intergovernmental Panel on Climate Change (IPCC) projects that the Middle East will be hotter and drier in future (IPCC Report, 2007; Shahraki et al., 2012; Sardar Shahraki et al., 2018). Climatically talking, Iran is located in arid and semi-arid zone of the world. Mean annual rainfall is 250 mm in Iran which is much lower than that of Asia and the world (732 and 831 mm, respectively). The precipitation rate is about 400 billion m^3 per annum in Iran, of which 270 billion m^3 is evaporated and transpired, and 130 billion m^3 can be utilized as renewable water resources. Assuming no change in per capita water consumption and projected population of 90.4 million by 2021, we will need 130-billion m^3 water in Iran. Obviously, it will be impossible to meet this demand by renewable water resources, turning the deficiency and quality loss of water resources into a serious challenge for our development plans (Ministry of Energy, 2011; Sardar Shahraki et al., 2018). The concept of water resources management was first emerged as a response to inappropriate use of water resources and its adverse consequences for environment and agricultural economics (Madani et al., 2014; Sardar Shahraki et al., 2018; Sardar Shahraki et al., 2019).

The Sistan region is frequently faced with serious events like flood and drought and has a unique situation due to its specific hydrological and spatial conditions. (Sardar Shahraki et al., 2019; Sardar Shahraki et al., 2018). Locating at the end of a closed basin, a complex hydrological system of the Hirmand river and meeting environmental requirements of the Hāmūn in severe conditions, and the blow of 120-day winds with slight annual precipitation (50 mm), high temperature, and low penetrability of soil on the one hand and the limited groundwater resources, shared surface water resources with neighboring country, and lack of governance on the origins of the Hirmand river in Iranian territory on the other hand have put the region in a unique condition (Sardar Shahraki et al., 2019; Sardar Shahraki & Aliahmadi, 2018). Therefore, the concept of multiple-attribute decision-making (MADM) and its application play a key role in integrated water management in the Sistan region. One important application of decision-making models is in the management and planning of water reservoirs in order to prioritize water supply and allocation schemes. Water resources management is influenced by multiple factors including social, economical and environmental factors. The objective of the present work was to prioritize the allocation of the water of *Chahnimeh* reservoir using fuzzy multiple-attribute decision-making (FMADM) models in the Sistan region.

2. Literature Review

This section summarizes some relevant studies. Rafiy Darani *et al*. (2007) used multiple-criteria procedure for irrigation management and the selection and ranking of irrigation systems in Isfahan Province, Iran. They compared and ranked irrigation systems for optimum irrigation management by criteria matrix, qualitative efficiency of alternatives, and compromise programming, and concluded that solid-set sprinkler irrigation was the best system. Barshandeh *et al*. (2012) applied multiple-criteria decision-making (MCDM) procedures in integrated water management in the west of Urmia Lake, Iran in which eight criteria were specified. Then, they were weighted by analytic hierarchy process (AHP) and ranked by SAW and TOPSIS method. In a study on the importance of criteria underpinning the performance of irrigation and drainage networks using AHP, Montazer *et al*. (2010) evaluated and compared triple regions of Sefīd-Rūd network. They considered technical, managerial, environmental, economical, and social criteria as decision-making criteria and considered 6, 7, 3, 8, and 3 sub-criteria for them, respectively. Their results revealed that the managerial criterion (with relative weight of 0.384) and environmental criterion (with relative weight of 0.09) had the strongest and weakest impact on network performance, respectively. Nader and Sabouhi (2011) studied the priorities of the allocation of Mahabad Dam water by fuzzy analytic hierarchy process (APH). After considering the decision-makers' opinions and deriving the weights of criteria, sub-criteria, and finally alternatives, they concluded that in final weights for the prioritization of water allocation to alternatives, the economical criterion (weight = 0.45) was of the highest importance and social criterion (weight = 0.23) was of the lowest importance. In addition, agricultural sector got the highest weight of 0.356. Zahedipour *et al*. (2013) prioritized water resource management practices by analytic hierarchy process (AHP) in Southern Khorasan Province. Razavi Toosi and Mohammadvali Samani (2014) stressed the importance of evaluating the impact of different water sector approaches and indices on basin management and the complex interrelationship between criteria and sub-criteria in economical, social, and environmental sectors. They used ANP and an integrated ANP and fuzzy TOPSIS method to evaluate basins. The comparison of the outputs of these two methods revealed that both methods prioritized the alternatives similarly. Dahimavy *et al*. (2015) examined the use of MCDM models in prioritizing water resource development plans in rural areas of Khuzestan Province. They first studied the irrigation and drainage projects and public contribution in the domain of Water and Power Organization of Khuzestan Province and defined the indices from officials' and farmers' perspective. Then, the projects were rated using SAW and WPM methods; thereby, their implementation with cooperative system was prioritized. Mei *et al*. (1989) used AHP for policy-making and water management in Beijing, China. Given the problem of water deficit in Beijing, they designed AHP in four levels and formulated 24 policies based on eight criteria. They found that decision-makers' qualitative and quantitative information about water influenced the policy-making and local prioritization process. Different authors about fuzzy MCDM like Chen and Hwang (1992) have proposed different methods for the prioritization of alternatives in terms of different criteria in the condition when there is just one decision-maker. Overall, numerous methods have been offered for the prioritization of alternatives in fuzzy environment including alternatives prioritization by making comparison with unfuzzied values (Adamo, 1980; Yager, 1980), by making comparison with index fuzzy sets (Jain, 1977; Chen, 1985), and by pairwise comparison of alternatives (Dubois and Prade, 1983). These methods are mostly used when just an individual expert’s opinions are utilized in weighting the criteria and evaluating the alternatives in terms of the criteria. The calculations are quite sophisticated in some of these methods. To cope with the drawbacks of the previous procedures, Raj and Kumar (1998) introduced a method for prioritizing water resources management alternatives under fuzzy conditions when there was more than one expert. The final utilities of alternatives were specified by using the maximum and minimum sets. This procedure was applied to prioritize the projects for the Krishna River basin in India (Sardar Shahraki *et al*., 2016) In a study on a water transfer scheme in South Africa to meet the industry requirements, Snaddon *et al*. (2001) examined the economical, social, geomorphological, political, and environmental consequence of the scheme. Srdjevic *et al*. (2004) showed the application of TOPSIS in the appraisal of water management scenarios and their prioritization. They determined system efficiency parameters temporally and spatially. Sasikumar and Mujundar (1998) introduced a fuzzy multiple-criteria model for the quality management of river systems. They addressed quality objectives of the agencies responsible for quality conservation of rivers and emitters of various pollutants to rivers in a fuzzy manner. Dinar and Yaron (2002) studied the adoption or abandonment of new irrigation technologies and found a significant relationship between the adoption of irrigation technologies and the variables of water price, crop price, and subsidy for irrigation equipment using decision-making models. They suggested that the government could manipulate these factors and thereby interfere in the development rate of irrigation methods. Morais and Almeida (2006) utilized Promethee-based MCDM model to select the best strategy for the leakage management in water supply systems. They aimed at finding the best leakage management strategy considering the perspectives of four main stakeholders and considered the budget as the constraint. Feng *et al*. (2005) proposed a decision-making support system for the evaluation of socio-economical impacts of water transfer scheme in order to check the transfer of water from south to north in China. Ánagnostopoulos et al. (2005) used AHP and

PROMTI multiple-criteria methods for water resources planning for the Nestos River, Greece. Boumaski et al. (2006) designed a decision support for water quality management for the Mesta River in Bulgaria. Simonovic and Verma (2008) applied TOPSIS method for the ranking of water resources management projects. Rudi (2009) used AHP for irrigation water allocation in the basin of the Tampo River in Indonesia. He considered the social aspect of water users, the physical aspect of water resources, and their interactions and stated that the relationships between these two aspects can be reasonably evaluated if ecological aspects are taken into account. In addition, the social aspects of users should not be overlooked when the physical water resources plans are implemented.

3. Methodology

The present work aimed to prioritize *Chahnimeh* water allocation using fuzzy multiple-attribute decision-making (FMADM) models, for which decision-making problem structure was first developed and then, alternatives were compared in terms of the criteria involved in decision-making. Finally, they were prioritized. According to what was said, fuzzy analytic hierarchy process (FAHP) and fuzzy technique for order preference by similarity of an ideal solution (FTOPSIS) were applied. They are described in the next sections.

3.1 Fuzzy Analytic Hierarchy Process

AHP reflects the inherent behavior and thoughts of mankind. In addition, it enjoys a robust theoretical basis and is founded on axioms. The method reflects the emotions and reasoning about issues in question and then, integrates various judgments in one conclusion that is consistent with people’s internal expectations. However, a subjective judgment is not mathematically precise and may create ambiguities in results. Therefore, AHP analysis for solving hierarchical problems was developed in response to this major drawback. In this analysis, decision makers usually make their judgments for an interval instead of a constant value, which is much more reliable. Hence, decision maker cannot have explicit preferences in fuzzy attribute of comparison process (Sardar Shahraki *et al*, 2016). AHP was first developed by Thomas L. Saaty in 1977 for helping the solution of complex multiple-criteria decision-making problems. The models of this method are developed as a complex decision-making problem in a descending hierarchical system in that the overall goal is placed in the uppermost level followed by criteria, sub-criteria and finally alternatives at the lowest level. The relative importance or preference between criteria and between alternatives within each criterion is determined by pairwise comparisons (Asgharpour, 2002). The pairwise comparisons matrix is formed in AHP as shown below (Lee & Dinar, 1995):

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{1n} & a_{2n} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (1)$$

Pairwise comparison matrix is implemented on the basis of decision maker's opinion and the elements of each level separately. Matrices include pairwise comparison between the studying criteria and the matrices of pairwise comparisons of the alternatives on the basis of each criterion. In total, if we have *m* alternatives and *n* criteria, the pairwise comparison matrix of alternatives will be in form of $m \times m$ and the pairwise comparison matrix for criteria will be an $n \times n$ matrix. The elements of pairwise comparison matrices are shown with a_{ij}. In AHP, it is assumed that $a_{ij} = 1/a_{ij}$. Thus, if $i = j$, then $a_{ij} = 1$ (Talebi, 2013). To assess the relative importance of *m* alternatives, they are compared in a pairwise manner. In other words, a certain alternative is not compared with the other alternatives simultaneously. At a specific time, it can be compared just with one another alternative (Asgharpour, 2002).

4. Procedure of FAHP

Step 1) drawing hierarchy tree: the decision hierarchy structure is drawn using the levels of goal, criteria, and alternatives.

Step 2) Forming pairwise judgment matrix: the matrices are formed according to decision tree and using experts' opinions in the form of triangular fuzzy numbers.

Step 3) Averaging the opinions: the arithmetic average of decision-makers' opinions is formed by the following matrix (Asgharpour, 2002):

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & (1,1,1) \end{bmatrix} \quad (2)$$

$$\tilde{a}_{ij} = \sum_{k=1}^{p_{ij}} a_{ijk} \Big/ p_{ij} \qquad i, j = 1, 2, ..., n \quad (3)$$

Step 4) Adding up the elements of each row:

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{a}_{ij} \qquad i = 1, 2, ..., n \quad (4)$$

Step 5) Normalizing:

$$\tilde{M}_i = \tilde{S}_i \otimes \left[\sum_{i=1}^{n} \tilde{S}_i \right]^{-1} \quad i = 1, 2, ..., n \quad (5)$$

If $\tilde{S}_i$ is displayed as (l_i, m_i, u_i), then Equation (5) will be calculated as follows (Zanjirchi, 2014; Asgharpour, 2002):

$$\tilde{M}_i = \left(l_i \Big/ \sum_{i=1}^{n} u_i \, , \, m_i \Big/ \sum_{i=1}^{n} m_i \, , \, u_i \Big/ \sum_{i=1}^{n} l_i \right) \quad (6)$$

Step 6) Determining the possibility degree of being greater: the possibility that each μ_i is greater than other μ_i's is estimated and is called $d'(A_i)$ (Zanjirchi, 2014; Asgharpour, 2002):

$$d'(A_i) = MinV\ (M_i \geq M_k) \qquad k = 1, 2, ..., n \quad k \neq i \quad (7)$$

Therefore, matrix weight vector is derived as follows (Zanjirchi, 2014; Asgharpour, 2002):

$$W' = [d'(A_i), d'(A_i), ..., d'(A_i)]^T \tag{8}$$

Step 7) Normalizing:

$$W = \left[d'(A_1) \Big/ \sum_{i=1}^{n} d'(A_i), d'(A_2) \Big/ \sum_{i=1}^{n} d'(A_i), ..., d'(A_n) \Big/ \sum_{i=1}^{n} d'(A_n) \right]^T \tag{9}$$

These weights are definitive (Unfuzzy) weights. The circulation of all matrices is derived by replicating this process.

Step 8) integrating the weights: the final weight of a certain alternative will be estimated by combining the weights of that alternative and the criteria (Zanjirchi, 2014; Asgharpour, 2002):

$$\tilde{U}_i = \sum_{j=1}^{n} \tilde{W}_i \tilde{r}_{ij} \qquad \forall i \tag{10}$$

Fuzzy technique for order preference by similarity of an ideal solution (FTOPSIS)

In fuzzy TOPSIS, a fuzzy decision-making matrix is formed including the preference ratio of alternatives based on the relevant criteria. Then, the fuzzy weighted matrix is derived by multiplying the fuzzy weight of criteria in normalized fuzzy matrix (Srdjevic *et al*., 2004). Chen and Hwang described FTOPSIS steps for an MCDM problem with *n* criteria and *m* alternatives as below:

I: *Decision matrix formation*

Given the number of criteria, the number of alternatives, and the evaluation of all alternatives for different criteria, decision matrix is formed as below (Darvishi *et al*., 2013):

$$\tilde{D} = \begin{bmatrix} \tilde{\chi}_{11} & \tilde{\chi}_{12} & \cdots & \tilde{\chi}_{1n} \\ \tilde{\chi}_{21} & \tilde{\chi}_{22} & \cdots & \tilde{\chi}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{\chi}_{m1} & \tilde{\chi}_{m2} & \cdots & \tilde{\chi}_{mn} \end{bmatrix} \tag{11}$$

If triangular fuzzy numbers are applied, $\tilde{\chi}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ will reflect the performance of the alternative i (i = 1, 2, …, m) with respect to the criterion j (j = 1, 2, …, n). If trapezoidal fuzzy numbers are applied, $\tilde{\chi}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$ will show the performance of the alternative i (i = 1, 2, …, m) with respect to the criterion j (j = 1, 2, …, n). If decision-making panel is composed of k members and the fuzzy ranking of kth decision-maker is $\tilde{\chi}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$ for triangular fuzzy number for i = 1, 2, …, m and j = 1, 2, …, n, given the criteria and combined fuzzy ranking of $\tilde{\chi}_{ij} = (a_{ij}, b_{ij}, c_{ij})$, the alternatives can be derived from the following equation (Srdjevic *et al*., 2004):

$$\begin{aligned} a_{ij} &= \underset{k}{Min}\left\{a_{ijk}\right\} \\ b_{ij} &= \sum_{k=1}^{k} b_{ijk} \Big/ k \\ c_{ij} &= \underset{k}{Max}\left\{c_{ijk}\right\} \end{aligned} \tag{12}$$

II: *Determination of weight matrix of criteria*

At this step, the importance degree of different criteria is defined as $\tilde{W} = \left[\tilde{W}_1, \tilde{W}_2, ..., \tilde{W}_n\right]$, in that if triangular fuzzy numbers are applied, each component of w_j (the weight of each criterion) is defined as $\tilde{W}_j = (\tilde{W}_{j1}, \tilde{W}_{j2}, \tilde{W}_{j3})$ and if trapezoidal fuzzy numbers are applied, each component of W_j is defined as $\tilde{W}_j = (\tilde{W}_{j1}, \tilde{W}_{j2}, \tilde{W}_{j3}, \tilde{W}_{j4})$. Assuming that the decision-making panel is composed of k members and the importance degree of kth decision-maker is $\tilde{W}_{jk} = (\tilde{W}_{jk1}, \tilde{W}_{jk2}, \tilde{W}_{jk3})$ (for triangular fuzzy numbers) for j = 1, 2, …, n, then combined fuzzy ranking of $\tilde{W}_j = (\tilde{W}_{j1}, \tilde{W}_{j2}, \tilde{W}_{j3})$ can be derived from Equation (13) (Darvishi *et al*., 2013).

$$W_{j3} = \underset{k}{Max}\{W_{jk3}\}, \quad W_{j2} = \sum_{k=1}^{K} W_{jk2} \Big/ k, \quad W_{j1} = \underset{k}{Min}\{W_{jk1}\} \tag{13}$$

III: *Fuzzy decision matrix transformation to comparable scale*

When x_{ij}'s are fuzzy, r_{ij}'s will be undoubtedly fuzzy, too. At this step of TOPSIS, scaling is used instead of complicated calculations for which the scales of different criteria need to be transformed into comparable scales using linear scale transformation. If the fuzzy numbers are triangular, the elements of matrix with comparable scales are derived for positive and negative criteria by the following equations (Srdjevic *et al*., 2004):

$$\begin{aligned} \tilde{r}_{ij} &= \left(\frac{a_{ij}}{c^*_j}, \frac{b_{ij}}{c^*_j}, \frac{c_{ij}}{c^*_j} \right) \\ \tilde{r}_{ij} &= \left(\frac{a^-_j}{c_{ij}}, \frac{a^-_j}{b_{ij}}, \frac{a^-_j}{a_{ij}} \right) \end{aligned} \tag{14}$$

Where:

$$\begin{aligned} c^*_j &= \underset{i}{Max}\, c_{ij} \\ a^-_j &= \underset{i}{Min}\, a_{ij} \end{aligned} \tag{15}$$

Therefore, fuzzy decision matrix with comparable scale ($\tilde{R}$) is derived as below (Srdjevic *et al*., 2004):

$$\tilde{R} = \left[\tilde{r}_{ij} \right]_{m \times n} \quad i = 1, 2, ..., m \; ; \; j = 1, 2, ..., n \tag{16}$$

and/or:

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \cdots & \tilde{r}_{1j} & \cdots & \tilde{r}_{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{r}_{i1} & \cdots & \tilde{r}_{ij} & \cdots & \tilde{r}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{r}_{m1} & \cdots & \tilde{r}_{mj} & \cdots & \tilde{r}_{mn} \end{bmatrix} \tag{17}$$

Where, m denotes the number of alternatives and n expresses the number of criteria (Srdjevic et al., 2004).

IV: *Weighted fuzzy decision matrix*

Given the weight of different criteria, weighted fuzzy decision matrix is calculated by multiplying the importance degree of a specific criterion in normalized fuzzy matrix, which is derived as below (Srdjevic et al., 2004):

$$\tilde{V}_{ij} = \tilde{r}_{ij}.\tilde{w}_j \tag{18}$$

Where, $\tilde{w}_j$ expresses the importance degree of the criterion C_j. Therefore, the weighted fuzzy decision matrix will be as follows (Srdjevic et al., 2004);

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m\times n} \quad i = 1,2,...,m \ ; \ j = 1,2,...,n \tag{19}$$

and/or:

$$\tilde{V} = \begin{bmatrix} \tilde{V}_{11} & \cdots & \tilde{V}_{1j} & \cdots & \tilde{V}_{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{V}_{i1} & \cdots & \tilde{V}_{ij} & \cdots & \tilde{V}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{V}_{m1} & \cdots & \tilde{V}_{mj} & \cdots & \tilde{V}_{mn} \end{bmatrix} \tag{20}$$

If fuzzy numbers are triangular, we have the followings for positive and negative criteria (Srdjevic et al., 2004):

$$\tilde{V}_{ij} = \tilde{r}_{ij}.\tilde{w}_j = \left(\frac{a_{ij}}{c^*_j}, \frac{b_{ij}}{c^*_j}, \frac{c_{ij}}{c^*_j}\right).(w_{j1}, w_{j2}, w_{j3}) = \left(\frac{a_{ij}}{c^*_j}.w_{j1}, \frac{b_{ij}}{c^*_j}.w_{j2}, \frac{c_{ij}}{c^*_j}.w_{j3}\right) \tag{21}$$

$$\tilde{V}_{ij} = \tilde{r}_{ij}.\tilde{w}_j = \left(\frac{a^-_j}{c_{ij}}, \frac{a^-_j}{b_{ij}}, \frac{a^-_j}{a_{ij}}\right).(w_{j1}, w_{j2}, w_{j3}) = \left(\frac{a^-_j}{c_{ij}}.w_{j1}, \frac{a^-_j}{b_{ij}}.w_{j2}, \frac{a^-_j}{a_{ij}}.w_{j3}\right) \tag{22}$$

V: *Finding fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FNIS, A^-)*

Fuzzy positive ideal solution and fuzzy negative ideal solution are defined as (Srdjevic et al., 2004)

$$A^* = \{\tilde{V}_1^*, \tilde{V}_2^*, ..., \tilde{V}_n^*\} \quad (23)$$

$$A^- = \{\tilde{V}_1^-, \tilde{V}_2^-, ..., \tilde{V}_n^-\} \quad (24)$$

Where, $\tilde{V}_i^*$ is the best value of criterion *i* among all alternatives and $\tilde{V}_i^-$ is its worst value among all alternatives. This value is derived from (Srdjevic et al., 2004):

$$\tilde{v}_j^* = \underset{i}{Max}\{\tilde{v}_{ij3}\} \quad i = 1, 2, ..., m \; ; \; j = 1, 2, ..., n \quad (25)$$

$$\tilde{v}_j^- = \underset{i}{Min}\{\tilde{v}_{ij1}\} \quad i = 1, 2, ..., m \; ; \; j = 1, 2, ..., n \quad (26)$$

Alternatives at A^* and A^- show the perfect positive ideal and the perfect negative ideal, respectively.

VI: *Calculation of distance from FPIS and FNIS*

The distance of each alternative from FPIS and FNIS is calculated by (Ravanshadnia & Bozorgmehr, 2014):

$$S_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*) \quad , \quad i = 1, 2, ..., m \quad (27)$$

$$S_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad , \quad i = 1, 2, ..., m \quad (28)$$

Where, $d(.,.)$ expresses the distance between two fuzzy numbers in that if (a_1, b_1, c_1) and (a_2, b_2, c_2) are two triangular fuzzy numbers, their distance will be:

$$d_v(\tilde{M}_1, \tilde{M}_2) = \left(\frac{1}{3}\left[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2\right]\right)^{1/2} \qquad (29)$$

And if (a_1, b_1, c_1, d_1) and (a_2, b_2, c_2, d_2) are two trapezoidal fuzzy numbers, their distance will be (Srdjevic *et al*., 2004):

$$d_v(\tilde{M}_1, \tilde{M}_2) = \left(\frac{1}{4}\left[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2 + (d_1 - d_2)^2\right]\right)^{1/2} \qquad (30)$$

The components $d(\tilde{v}_{ij}, \tilde{v}_j^*)$ and $d(\tilde{v}_{ij}, \tilde{v}_j^-)$ are deterministic numbers.

VII: *Calculation of closeness coefficient*

Closeness coefficient is derived from (Asgharpour, 2002):

$$CC_i = {S_i^-}\big/{(S_i^+ + S_i^-)} \qquad \forall i = 1, 2, ..., m \qquad (31)$$

VIII: *Ranking of alternatives*

At this step, the alternatives are ranked in terms of closeness coefficient so that alternatives with high closeness coefficients are ranked the top.

Data were collected in two phases. The first phase was related to the theoretical basis of the topic in question and a review of literature which was carried out by library method. The second phase included data collection from local informed people and experts from Regional Water Affairs Agency, Jahad-e Agriculture Organization, and professors in local universities by a questionnaire. The questionnaire was designed on the basis of the objectives, questions, and hypotheses of the study after a review of literature and works done on the water allocation of *Chahnimeh* reservoirs. Then, its validity and reliability was estimated by Cronbach’s alpha that was found to be 0.89, showing high reliability of the questionnaire. Table 1 presents the studied alternatives that were selected on the basis of different parameters under different economical, social, and environmental approaches.

Table 1: The Parameters Studied in the Prioritization of Water Allocation

Parameters	Welfare	Income Generation	**Alternatives**	Agriculture
	Population Growth	Cultivation Area		Environment
	Downstream Ecosystem	Tourism Attraction		Drinking Water
	Water Quality	Job Creation		Industry And Services
	Dust Fixation			Entertainment And Tourism

5. Results and Discussion

Results based on different economical, social, and environmental approaches are presented here using fuzzy analytic hierarchy process (FAHP) and fuzzy technique for order preference by similarity of an ideal solution (FTOPSIS).

5.1 FAHP Results

Data were collected from 25 experts in relevant organizations using a questionnaire. The data were applied just after the questionnaire was shown to be valid and reliable. This section presents the results of FAHP under different economical, social, and environmental approaches. Figure 1 depicts results of FAHP for the optimum allocation of *Chahnimeh* water reservoir under economical approach.

According to the results shown in Figure 1 under economical approach, the water allocation of *Chahnimeh* is prioritized as follows. Agricultural sector is in the uppermost priority with the weight of 0.4. In other words, if economical issues are taken into account, this sector has the first priority. The second priority was found to be related to environment with the weight of 0.254. Since majority of people in the Sistan region rely on agricultural and environmental sectors for their subsistence, these two sectors were found to be in higher priority than other sectors. Entertainment and tourism sector had the weight of 0.144 and was ranked the third, showing its importance in economics. Industrial and service sector and drinking water were placed in the lowest ranks from an economical perspective.

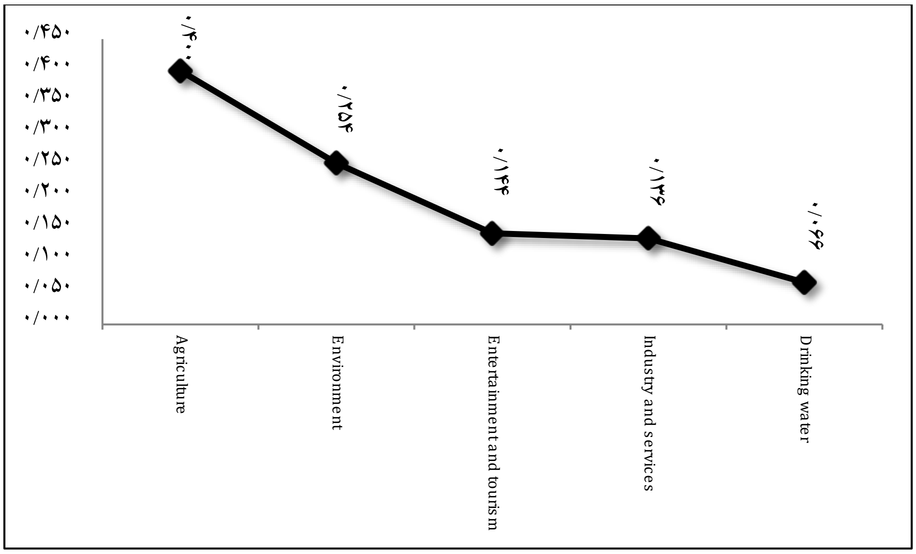

Figure 1: Results of Optimum Prioritization of Water Resources from Economical Perspective Using FAHP Technique

Figure 2 shows the results for the optimum allocation of *Chahnimeh* water reservoir from a social perspective found by FAHP.

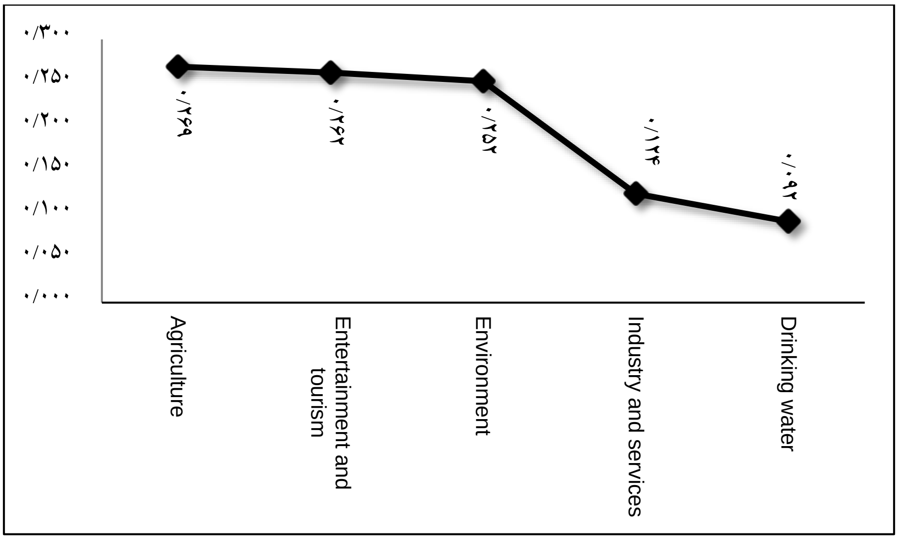

Figure 2: Results of Optimum Prioritization of Water Resources from Social Perspective Using FAHP Technique

Looking from a social perspective, agricultural sector (weight = 0.269) still is the top priority in enjoying the water reservoirs of

Chahnimeh in the Sistan region, but it was found to have lower weight in social perspective than in economical perspective. The second priority in the use of water was devoted to entertainment and tourism sector, showing its high importance in this perspective. Social perspective prioritized tourism in higher rank than economical perspective. Environmental sector got a lower rank in social perspective as compared to its rank in economical perspective. Industry and service sector and drinking water sector were also ranked the lowest with the weights of 0.124 and 0.092, respectively.

Figure 3 shows the results of the optimum allocation of *Chahnimeh* water reservoir using FAHP technique.

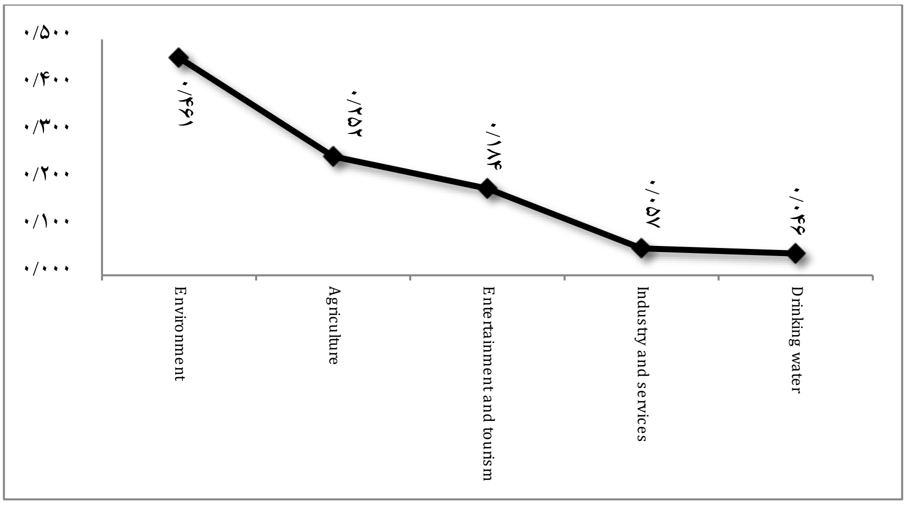

Figure 3: Results of Optimum Prioritization of Water Resources from Environmental Perspective Using FAHP Technique

From an environmental perspective, according to which environmental sector (weight = 0.461) was ranked the first because of its importance in contrary to economical and social perspectives. Agricultural sector was found to be in the second rank of priority. The next ranks were devoted to entertainment and tourism sector, industry and service sector, and drinking water sector. Since environmental perspective addresses the importance of lagoons and local environment, the expert gave this sector a specific attention, giving it the highest weight.

5.2 Results of Fuzzy Technique for Order Preference by Similarity of an Ideal Solution (FTOPSIS)

As was mentioned, two techniques were used to prioritize allocation of *Chahnimeh* water reservoir in order to minimize the error. The second technique was FTOPSIS. Like FAHP, the technique was performed from economical, social, and environmental perspectives.

Figure 4 shows results of optimum prioritization of water allocation from economical perspective using FTOPSIS.

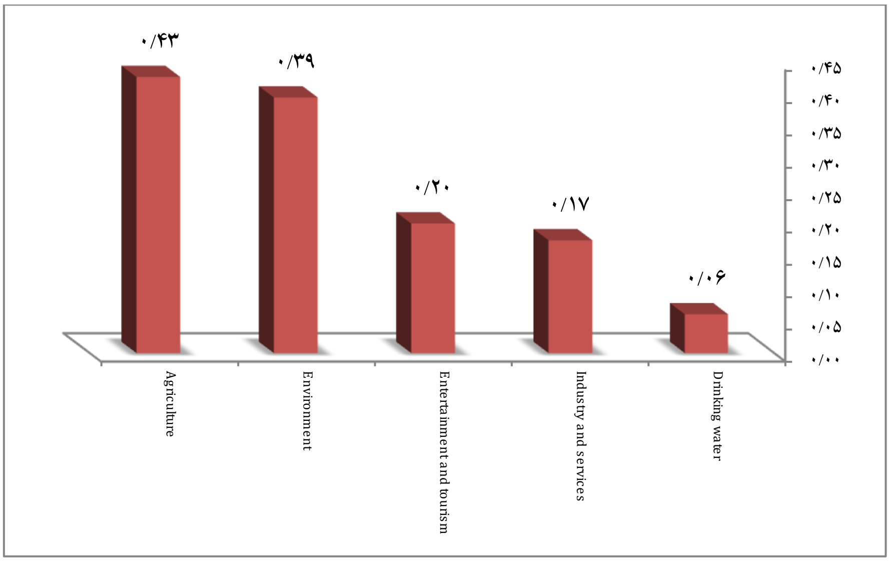

Figure 4: Results of Optimum Prioritization of Water Resources from Economical Perspective Using FTOPSIS Technique

This perspective prioritized agricultural sector in the first rank, as was the case in FAHP. The second rank was related to environmental sector with final weight of 0.39. From economical perspective, entertainment and tourism sector was prioritized the third with the weight of 0.20. Industry and service sector and drinking water sector were placed the lowest ranks.

Figure 5 depicts the prioritization of water allocation to different sectors using FTOPSIS.

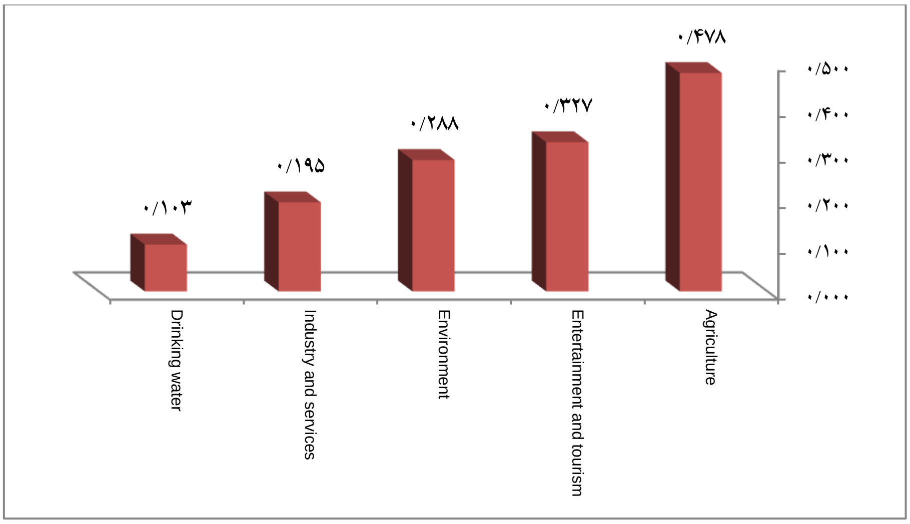

Figure 5: Results of Optimum Prioritization of Water Resources from Social Perspective Using FTOPSIS Technique

According to results, agricultural sector was ranked the first with the final weight of 0.48, entertainment and tourism sector was ranked the second with the weight of 0.327, environmental sector was ranked the third with the weight of 0.288, and industry and service sector and drinking water sector were ranked the fourth and fifth with the weights of 0.195 and 0.103, respectively. Results of FTOPSIS confirm the prioritization resulted from FAHP for the optimum allocation of *Chahnimeh* water allocation from social perspective.

Figure 6 shows the prioritization of water allocation by FTOPSIS from environmental perspective.

The results confirm results of FAHP from environmental sector depicted in Figure 3. According to the results, environmental sector was prioritized in the uppermost rank followed by agricultural sector in the second rank, entertainment and tourism sector in the third rank, and industry and service sector and drinking water sector in the next ranks.

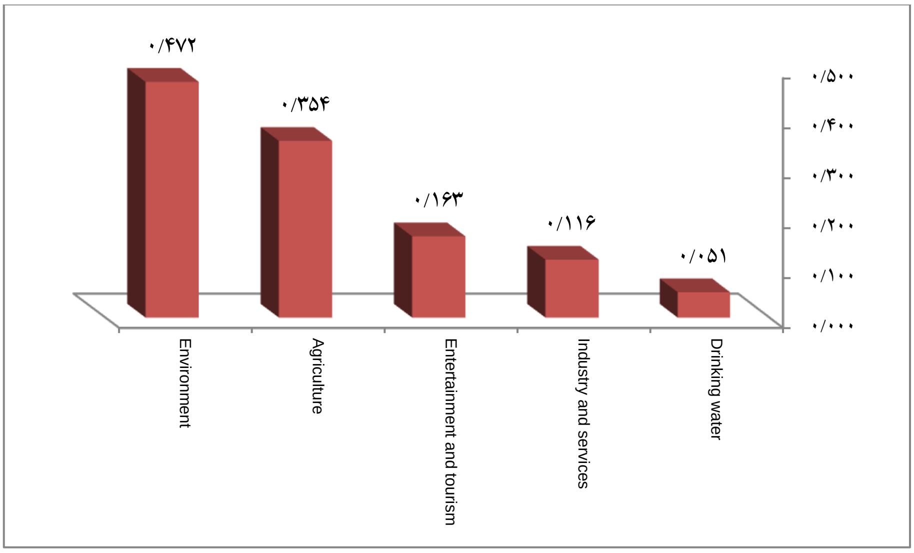

Figure 6: Results of Optimum Prioritization of Water Resources from Environmental Perspective Using FTOPSIS Technique

6. Recommendations

Economical perspective was found to be more important than the other two perspectives, i.e. social and environmental perspectives, which is justifiable because of the economical and social conditions of the studied region. Given the geographical conditions of the region and location of the province where there is a lack of industrial factories, it can be seen that the conditions pave the way for the emergence of smaller industrial and manufacturing plants. This plays an important role in the establishment of these plants and job creation. The next priorities of the criteria were related to social and environmental perspectives. On the other hand, since most people in Sistan are engaged in agriculture and agricultural sector was prioritized the top in all studied perspectives (especially in economical perspective) then officials should attempt more to boom this sector.

Agricultural sector gained the highest weight in two perspectives, i.e. economical and social perspectives. In this sense, attempts to claim water rights from Afghanistan (which amounts to 820 million m^3) will help the development of this sector a lot. On the other hand, water resources development plans approved by the government can play a significant role in meeting water requirements of agricultural sector. The enhancement of irrigation efficiency by pressurized systems is an example of these plans. Thus, officials have a dramatic role to play to improve agriculture by claiming water rights and fulfillment of the relevant projects.

According to the prioritizations, such practices as equipping, rehabilitation, and construction of promenades and entertainment centers can help realizing different objectives including tourism attraction to the Sistan region, which can, in turn, lead to the economical prosperity and also the creation of safe environment and conservation of *Chahnimeh* reservoirs.

Given the results from environmental perspective and the top priority of environment and Hāmūn lagoon as the representative of this sector, a great care should be given to the three lagoons of Hāmūn. Research shows that Hāmūn lagoon has been suffered from extensive damages in drought periods, for which it is recommended to conserve this lagoon for the use of the next generations and also the existing generation in the coming years. In other words, this ecosystem should be managed sustainably for the sake of the rights of the existing generation and the next generations to use it. In addition, investments are required to be made on this lagoon. MCDM can create a proper decision-making environment and help developing different managerial scenarios. Therefore, local water allocation officials are recommended to exercise these practices in the optimum management and exploitation of reservoir dams and other water resources.

Interview with experts reveals that there is no elaborate plan in spite of the critical conditions of water in the Sistan region. Hence, it is recommended to develop the policies, long-term strategies, and plans of water allocation and exploitation based on the present conditions of the region.

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