Ranking Inter-Basin Water Transfer Projects

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Abstract

One of the best ways to control water shortages in the Central region of Iran is inter-basin water transfer (IBWT). Efficient decision making on this subject is however a real challenge for the water authorities in Iran. These decisions should include multiple attributes, model uncertainty, and also the optimistic/pessimistic view of the decision makers.

The Ordered Weighted Averaging (OWA) operator can be used as an efficient multi-attribute decision making (MADM) method. This paper will introduce a new method to obtain the order weights of this operator. The new method is based on the combination of fuzzy quantifiers and neat OWA operators. Fuzzy quantifiers are usually applied in soft computing to model the optimism degree of the decision maker. In using neat operators, the ordering of the inputs is not needed resulting in better computation efficiency. The theoretical results will be illustrated in a case study by solving an MADM problem with four IBWT projects for the Zayanderud basin. The results demonstrate that more sensitive decisions can be obtained by using the new method.

1. INTRODUCTION

The increasing conflict among the stakeholders for the limited water resources and the relative absence of new and less expensive resources are usual characteristics of all water resources systems. These systems should be designed and managed by considering the present and future objectives of the society including social, economic, and environmental issues. Efficient decision making is therefore a complex problem.

This study develops a new extension of OWA, which is a special MADM method. Since the pioneering work of Yager (1988) the OWA operator is used in many fields including water resources management problems. Despic and Simonovic (2000) compared the OWA with three other methods to select flood control measures in Manitoba, Canada. Yalcin and Akyurek (2004) applied OWA for mapping flood vulnerability in a basin in Turkey. They used it as an aggregation operator to merge GIS (Geographical Information System) maps of various risk factors. There are two optional tools in the decision making module within IDRISI (2006) as GIS software: one is a simple additive weighting and the other is OWA. In applying OWA in multi-objective optimization, McPhee and Yeh (2004) selected three criteria to choose scenarios in aquifer management. Fu et al. (2006) developed climate change scenarios for the global mean temperature of 2050. They aggregated the possible scenarios based on their probabilities by using the OWA approach. The European commission developed MULINO (2006) as a decision support system (DSS) for integrated water resources management. It contains three methods including OWA. Makropoulos and Butler (2006) used the OWA in urban water management. They extended it to Spatial OWA (SOWA) by applying it in GIS to produce prioritization maps for pipe replacement in a water distribution network.

This paper introduces a new version of OWA, which will be applied to solve a practical problem for selecting IBWT projects. The paper develops as follow. The next section introduces the multi-attribute case study with IBWT projects. Then the details of the new method, called the Revised OWA, will be described. Next the IBWT projects will be compared by using the new method. The last section concludes the paper.

2. IBWT PROJECTS FOR CENTRAL IRAN

Iran is an arid / semi-arid country. Mean annual rainfall of the country is about 250 mm which is about 30% of the world average. The increasing water demand has caused an alarming decrease in annual per capita water resources. The uneven distribution of water across the country and the fast growth of the population have led to the present water shortages in major parts of the country, especially in the Central zone and in the Southeastern regions. Therefore by the year 2025 Iran is expected to fall in the group of countries with critical water shortages.

The country is divided into six main hydrological basins as shown in Figure 1 (WRMC, 2003). The main basins are: Caspian see (1), Uremia Lake (2), Persian Gulf and Oman Sea (3), Central (4), Hamoun (5), and Sarakhs (6). The annual per capita water resources potentials in the main basins are shown in Figure 2 for the year 2000.

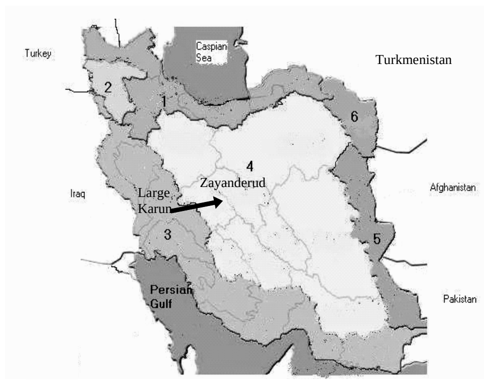

Figure 1. Main basins of Iran and IBWT projects positions to the Zayanderud basin

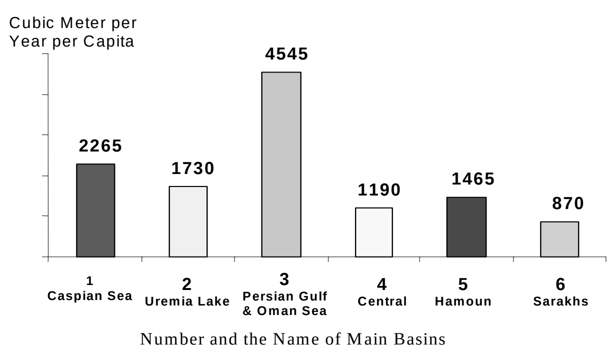

Figure 2. Water resources potentials in the main basins of Iran

According to Figure 2, the main basin 3 (Persian Gulf and Oman Sea) has the highest amount of water resources (~4545 cubic meter/capita/year) while the neighboring main basin 4 (Central) has only a quarter of that amount (~1190 cubic meter/capita/year), which is facing a high degree of water shortage. The socio-economic life of the people in Central basin can be improved by water transfer from a neighbor basin, Large Karun, which is located in the Southwest corner of the country. It is the most important basin in Iran with respect to water potentials and the possibility of further water resources development. The average long-term rainfall of Large Karun is about 760 mm. Part of its water potential is utilized inside the basin and transferred to other basins. The remaining water amount, around

20 to 25 billion cubic meters per year, is spilled and lost through outflow into the Persian Gulf. Part of the domestic and industrial wastewater returns to ground water aquifers or to surface drainages. The assessment of the overall water quality of the system (Large Karun) shows that the IBWT projects from the upstream will worsen the water quality in the downstream. Due to the high potential of growth in the Karun basin, there are various concerns about water transfers to the other basins, which generates conflicts among the stakeholders. Therefore it is essential to evaluate any possible IBWT project from Large Karun before implementation.

In this study we focus on the IBWT projects to the Zayanderud basin. It is located West of the Central basin as shown in Figure 1. It has a population around four millions and in recent years, this basin is developed very extensively. In order to meet the increasing water demand in this basin, four IBWT projects (Cheshmelangan, Kuhrang-III, Gukan and Behestabad) have been developed to transfer water from the Large Karun River. These projects transfer water to the Zayanderud River, which passes through Isfahan, an important and historical city of the country. The city attracts around one million domestic and foreign tourists in every year.

The Isfahan Regional Water Company as the Decision Maker (DM) wants to compare these IBWT projects. Before evaluating these projects, it is necessary to construct a general hierarchy of the criteria. In the first step, major watershed's plans of twenty countries were examined including plans from Turkey, Pakistan, India, Kenya, Sweden, United States, and Brazil. Based on the state-of-the-art reviews and the national acts of Iran, preliminary hierarchy was then introduced (Ardakanian and Zarghami, 2004). In order to revise, simplify and finalize the preliminary hierarchy, Value Management methodology was used by thirty experts. Value Management is a style of management particularly dedicated to motivate people, develop skills and promote synergies and innovation, with the aim of maximizing the overall performance of a system. This method was pioneered by Miles (2006) in the 1940's and 50's and in our study, the concept of value is based on the following relationship:

$$Value = \frac{Satisfaction\ of\ the\ needs}{Use\ of\ resources}. \tag{1}$$

In conducting the Value Management study stakeholders were selected from the Government, consulting companies, universities and also from NGOs (Non Governmental Organizations). The revised hierarchy is shown in Figure 3, consisting of seven main criteria and thirty two attributes. The main criteria are social and cultural, political, security and legal, technical and executive, environmental, economical and financial, demand management and comprehensive management.

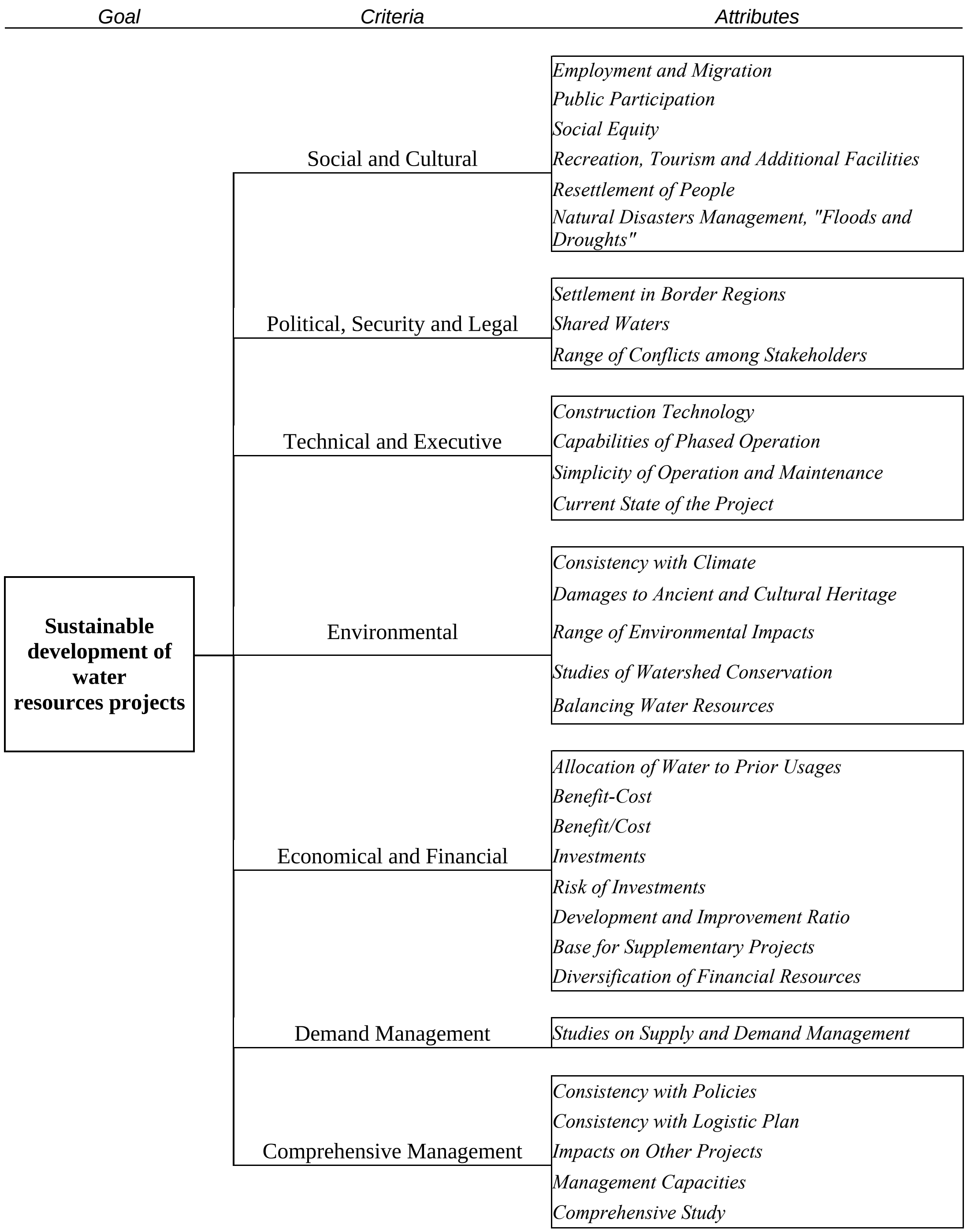

Figure 3. Hierarchy of criteria for the evaluation of the projects

In this case study, only seven attributes were selected from the hierarchy, since some of them were irrelevant to the IBWT projects and also there was a lack of reliable data to evaluate the projects with respect to some of them. The finally selected attributes and their definitions are as follows:

- **Allocation of water to prior usages**: Domestic, industrial, agricultural, environmental and recreational water usages have to be prioritized.
- **Diversification of financial resources**: The governmental budget for the construction of the projects is limited and uncertain. It is therefore an advantage of a project if it has other financial resources from the private sector or from foreign funds.
- **Resettlement of people**: Any IBWT needs a reservoir in its origin and consequently it requires relocating the people from that area. However it is a negative attribute and may create social hazard.
- **Public participation**: IBWT projects create social conflicts in the region. If the people have higher participation in relocation related decisions, in selling their lands, in labour supply and in regulating their water rights, then the project will be accepted more easily and can become successful.
- **Consistency with policies**: How much consistency is between the alternatives and the national, regional and local policies?
- **Benefit/cost**: This is an index for the financial efficiency of the projects.
- **Range of environmental impacts**: These impacts are assumed to be negative.

The data of evaluating the alternatives with respect to the above seven criteria is presented in Table 1. They were obtained by using a group of experts from the DM's company. The uncertainty of the data is represented by using either triangular fuzzy numbers or linguistic variables. A general fuzzy number is defined by its membership function. We used triangular form which is shown in Figure 4. In the case of linguistic variables we used: Very Low (VL), Low (L), Slightly Low (SL), Medium (M), Slightly High (SH), High (H), and Very High (VH).

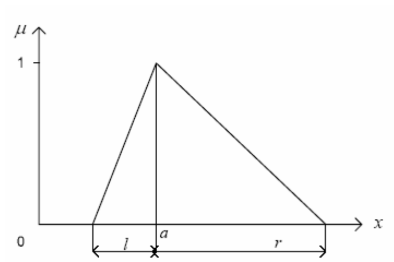

Figure 4. A triangular fuzzy number (*a, l, r*)

Table 1. Evaluation matrix of IBWT projects

		Attributes						
		Allocation of Water to Prior Usages	Diversification of Financial Resources	Resettlement of People	Public Participation	Consistency with Policies	Benefit/Cost	Range of Environmental Impacts
		Weights of attributes						
Alternatives		VH	M	VH (Negative)	L	H	M	SL (Negative)
1	Gukan	SH	(5.0, 1.0, 1.0)	(0.0, 0.0, 0.1)	SH	H	(1.5, 0.1, 0.1)	L
2	Cheshmelangan	VH	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.1)	M	VH	(1.4, 0.3, 0.3)	M
3	Kuhrang-III	VH	(3.0, 1.0, 1.0)	(200.0, 50.0, 50.0)	H	VH	(1.1, 0.3, 0.3)	SL
4	Beheshtabad	VH	(4.0, 1.0, 1.0)	(4000.0, 50.0, 50.0)	VH	H	(1.6, 0.3, 0.3)	SH

3. METHODOLOGY

The comparison of the decision alternatives given in Table 1 is based on their combined goodness measures. OWA can be used to aggregate the evaluations of each alternative with respect to the criteria. An *n*-dimensional OWA operator assigns a combined goodness measure for each alternative:

$$F(a_1, a_2, ..., a_n) = \sum_{j=1}^{n} w_j b_j = w_1 b_1 + w_2 b_2 + ... + w_n b_n \ , \tag{2}$$

where $F : I^n \mapsto I$ with $I = [0,1]$, b_j is the *j*th largest element in the set of $\{a_1, a_2, ..., a_n\}$, the evaluations of an alternative with respect to the *n* criteria, and w_j $(j = 1, 2, ..., n)$ are the order weights such that $w_j \geq 0$ and $\sum_{j=1}^{n} w_j = 1$. That is, the OWA operator is a convex linear combination of the b_j values. Notice that the components of the input vector have been ordered before multiplying them by the order weights. The OWA method has a large variety by the different selections of the order weights. Order weights depend on the optimism degree (well known as Orness degree) of the DM. The greater the weights at the beginning of the vector are, the higher is the optimism degree. Yager (1988) defined the optimism degree θ as:

$$\theta = \frac{1}{n-1} \sum_{j=1}^{n} (n-j) w_j \ . \tag{3}$$

Xu (2005) gives a general overview of the different methods for determining the order weights. In the next section, we will introduce the new method, called the Revised OWA.

4. REVISED OWA

In natural language we use many linguistic terms such as *most, few, many*, and *about half*. Zadeh (1983) called them linguistic quantifiers. Classical logic uses only two of these terms; the existential quantifier, *there exist*, and the universal quantifier, *all*, in forming logical propositions (Yager, 1996). Zadeh (1983) suggested the modeling of these linguistic quantifiers by using fuzzy sets. In this paper these linguistic inputs are modeled by Regular Increasing Monotonic (RIM) quantifiers. An RIM quantifier, Q, characterizes aggregation imperatives, in which higher satisfaction is obtained by including more objects. This quantifier has the following properties:

$$R(Q) = [0,\ 1], \quad Q(0) = 0\ , \quad Q(1) = 1 \ \text{ and } \ Q(r_1) \geq Q(r_2) \quad \text{if} \quad r_1 \geq r_2 . \tag{4}$$

Yager (1988) suggested obtaining the weights of an n-dimensional OWA operator as

$$w_j = Q(\frac{j}{n}) - Q(\frac{j-1}{n}), \quad j = 1\ ,\ 2\ ,\ ...,n. \tag{5}$$

Notice first that the derivative of the fuzzy quantifier Q is as follow:

$$\frac{dQ}{dr} = \lim_{\Delta r \to 0} \frac{Q(r) - Q(r - \Delta r)}{\Delta r}. \tag{6}$$

In the special case when n is large we may select $\Delta r = 1/n$, and so

$$\frac{dQ}{dr} \approx \frac{Q(r) - Q(r - 1/n)}{1/n}.$$

Yager (1993) evaluated the value of dQ/dr at $r = j/n$ by using equation (5) as

$$\left.\frac{dQ}{dr}\right|_{r=j/n} \approx \frac{Q(j/n) - Q((j-1)/n)}{1/n} = \frac{w_j}{1/n}$$

so

$$w_j \approx \frac{1}{n} \left.\frac{dQ}{dr}\right|_{r=j/n}. \tag{7}$$

These weights depend on only the order of the criteria. More accurate weight selection can be obtained if the weights depend on also the evaluations of the criteria. So instead of using equation (7), we propose the following weight selection:

$$w_j = \frac{1}{n} \left.\frac{dQ}{dr}\right|_{r=1-b_j} \tag{8}$$

where $b_1 \geq b_2 \geq ... \geq b_n$ or $(1-b_1) \leq (1-b_2) \leq ... \leq (1-b_n)$. The reason of using the term (1-b_j) instead of b_j is due to the opposite ordering of the criteria in equation (7) in comparison to the ordering of the b_j values in the case of RIM quantifiers.

These values however do not satisfy the necessary conditions of OWA weights since their sum usually differs from unity. After normalizing the w_j values in equation (8), the final weights are obtained as follow:

$$w_j = \frac{Q^{'}(1-b_j)}{\sum_{l=1}^{n} Q^{'}(1-b_l)}. \tag{9}$$

This method of weights selection is called Revised OWA since it is based on the exact derivatives of the quantifier. The weights obtained by equation (9) satisfy all necessary conditions of the OWA weights. The Revised OWA operator with weights (9) and with any fuzzy quantifier is a neat operator since the combined goodness measure, F is independent of the ordering of the inputs:

$$F(a_1,\ a_2,\ ...,\ a_n) = \sum_{j=1}^{n} w_j\ b_j = \sum_{j=1}^{n} \frac{Q^{'}(1-b_j)}{\sum_{l=1}^{n} Q^{'}(1-b_l)} b_j = \sum_{j=1}^{n} \frac{Q^{'}(1-a_j)}{\sum_{l=1}^{n} Q^{'}(1-a_l)} a_j = \frac{\sum_{j=1}^{n} Q^{'}(1-a_j) a_j}{\sum_{l=1}^{n} Q^{'}(1-a_l)}. \tag{10}$$

An additional advantage of using neat OWA operators in comparison to the initial OWA is due to the fact that in this case more attention is given to the context of the problem (e.g. to the evaluation values b_j). It is however a disadvantage of Revised OWA that the weights have to be calculated separately for each alternative.

5. RANKING THE IBWT PROJECTS

We can now return to the case study introduced earlier (second Section). The combined goodness measures of four IBWT projects are determined by using the Revised OWA. The calculation procedure is as follows:

Step 1. At the beginning, the evaluations of the projects with respect to the attributes were either linguistic variables or triangular fuzzy numbers. The linguistic data were modeled by crisp numbers according to the uniform scale shown in Table 2. Other scales could also be introduced based on non-uniform distributions. All triangular fuzzy numbers were also defuzzified by using the centroid method.

Table 2. Linguistic variables and equivalent crisp numbers

Linguistic Variables	Number
Very Low	0.05
Low	0.20
Slightly Low	0.35
Medium	0.50
Slightly High	0.65
High	0.80
Very High	0.95

Step 2. The evaluations of the alternatives with respect to the attributes have been normalized into the unit interval [0, 1] as follows:

$$a_i = \begin{cases} \dfrac{A_i}{\underset{1 \le j \le n}{Max}(A_j)} & \text{for positive criteria,} \\ \\ \dfrac{\underset{1 \le j \le n}{Min}(A_j)}{A_i} & \text{for negative criteria.} \end{cases} \tag{11}$$

Step 3. In the original version of OWA, the attribute weights are considered to be equal, however in this case, they are not equal as it is shown in the first row of Table 1. These weights are multiplied by the evaluations of the alternatives after they are normalized in step 2.

Step 4. The order weights are determined by using equation (9). Table 3 shows the results for the alternative Gukan.

Table 3. The OWA weights for the alternative Gukan

Quantifier/ Situation		Optimism degree	w_1	w_2	w_3	w_4	w_5	w_6	w_7
All		0.001	*0.000*	*0.000*	*0.000*	*1.000*	*0.000*	*0.000*	*0.000*
Most	*Pessimistic*	0.091	*0.071*	*0.012*	*0.000*	*0.910*	*0.000*	*0.007*	*0.000*
Many		0.333	*0.199*	*0.162*	*0.100*	*0.264*	*0.015*	*0.153*	*0.107*
Half	*Neutral*	0.500	*0.143*	*0.143*	*0.143*	*0.143*	*0.143*	*0.143*	*0.143*
Some		0.667	*0.095*	*0.105*	*0.134*	*0.083*	*0.344*	*0.109*	*0.130*
Few	*Pessimistic*	0.909	*0.056*	*0.067*	*0.104*	*0.043*	*0.562*	*0.071*	*0.098*
At least one		0.999	*0.047*	*0.058*	*0.094*	*0.036*	*0.615*	*0.062*	*0.088*

Step 5. The combined goodness measures have been finally calculated by using equation (10). The results are shown in Figure 5.

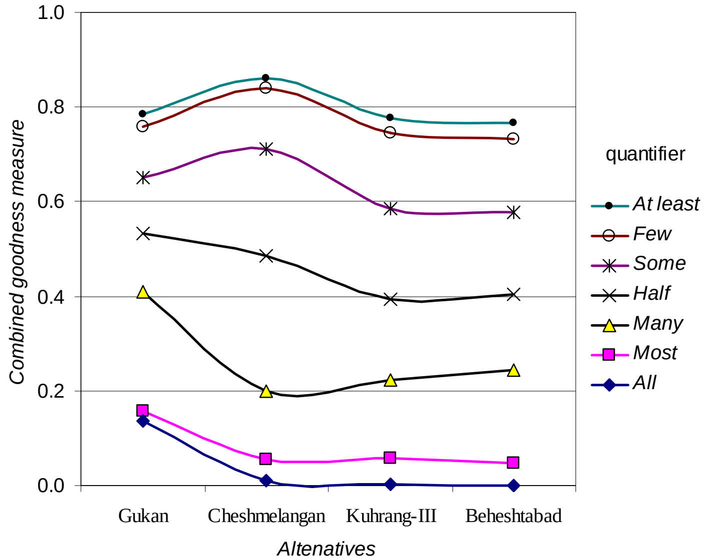

Figure 5. The combined goodness measures of IBWT projects

According to Figure 5, Cheshmelangan is the most preferred project when the DM is optimistic (based on the quantifiers *At least, Few* and *Some*). Gukan is however the most preferred project if the DM is neutral (by the quantifier *half*) or pessimistic (by the quantifiers *Many, Most* and *All*).

The corresponding ranks of the alternatives are shown in Table 4. The first column 'current state of project' reflects the previous decisions of the DM in which Cheshmelangan is in operation (rank 1), Kuhrang-III is under construction (rank 2), Gukan is in the final study (rank 3) and Beheshtabad is under investigation (rank 4).

Table 4. Ranks of IBWT projects

Alternatives	Current State of the projects	Fuzzy quantifiers						
		All	*Most*	*Many*	*Half*	*Some*	*Few*	*At least*
Gukan	3	1	1	1	1	2	2	2
Cheshmelangan	1	2	3	4	2	1	1	1
Kuhrang-III	2	3	2	3	4	3	3	3
Beheshtabad	4	4	4	2	3	4	4	4

The most and least preferred projects, according to the column 'current state of project', are the same as in the columns of *some*, *few* and *at least* which represent the optimistic view of the DM. Therefore we can conclude that the DM was optimistic about the IBWT projects. Water managers are usually not risk-taking individuals. However in the case of Zayanderud, the DM is water recipient and not water supplier. He/she wants to bring as much water as possible to the Zayanderud basin, which explains the optimistic view.

However the optimism degree of the DM is also subject to the national and local policies. If the DM felt to be pessimistic due to the risky conditions, the Gukan project would have been the most preferred project. The ranks of the other projects also depend on the optimism degree. As an illustration, a sensitivity analysis was performed on the ranks of the alternatives due to the changes of the optimism degree. The interval [0.01, 0.99] was selected with the increment of 0.03 and the entire procedure was repeated for all particular values of the optimism degree. The results are shown in Figures 6 through 9, which illustrate the dependence of the preference order on the optimism degree, or how the ranks would change by the dynamic feature of the optimism degree.

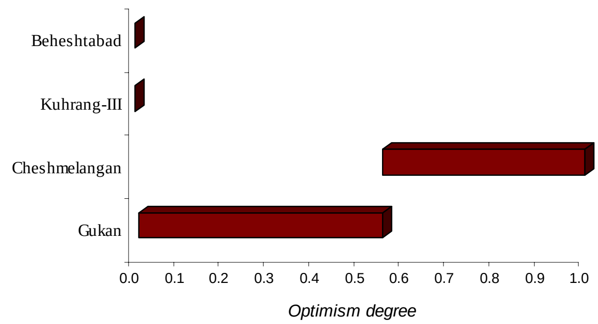

Figure 6. Most preferred alternatives

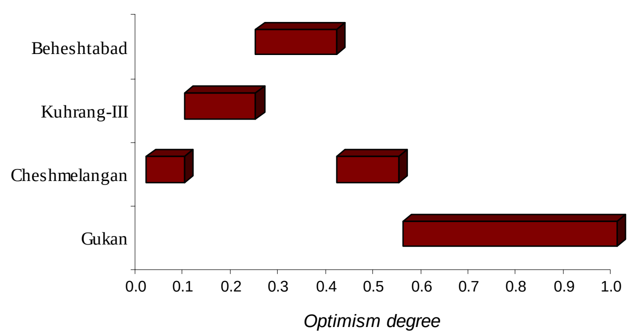

Figure 7. Second most preferred alternatives

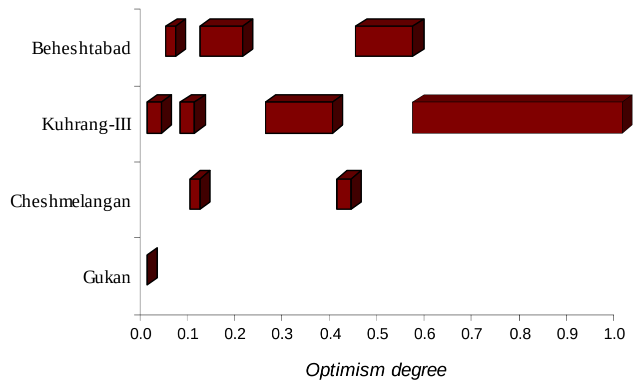

Figure 8. Third most preferred alternatives

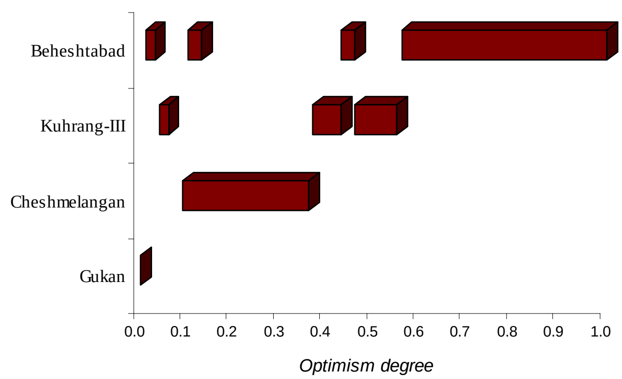

Figure 9. Least preferred alternatives

According to Figures 5 through 9, the ranks of the projects are robust in the entire optimistic section (θ>0.5). However in the pessimistic section their dependence on the optimism degree is not monotonic. Therefore the precise knowledge of the optimism degree of the DM in the pessimistic region (θ<0.5) is very important for securing the safe and satisfactory decision.

6. CONCLUSIONS

The Revised OWA operator was introduced and applied successfully in ranking IBWT projects for Zayanderud, Iran. The results of this study show that this new method is better than the other traditional MADM methods (Hwang and Yoon, 1981 and Zarghami et al 2007) since it reflects the optimism/pessimism nature of the DM by using a quantifiable method. The comparison of the obtained results with the current state of the projects shows the optimistic character of the DM.

Revised OWA uses fuzzy quantifiers to achieve a better characterization of the DM's satisfaction. It is therefore a context based model in which the ordering of the initial inputs is not required, so it is a neat operator. This new method therefore offers a more efficient way of computing the OWA weights. A sensitivity analysis illustrated the dependence of the rankings on the optimism degree of the DM.

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