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Group Decision Support System for Ranking of Water Resources Projects

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Abstract

Several stakeholders share the national water resources projects in Iran and resolving the conflict among them is one of the major challenges of the water division of the Government. In this paper a group decision support system will be developed to identify the criteria and their weights, needed for ranking the national water resources projects. This model will be based on extending the concept of Ordered Weighted Averaging (OWA) as an aggregation operator. The order weights of this operator will be determined first by using the fuzzy quantifiers method. Second, a new measure will be developed to quantify consensus among the stakeholders. It guides the client of the GDM problem to negotiate with stakeholders effectively in the conflict resolution process. In addition, a new sensitivity analysis model will be introduced for the weights of the criteria with respect to the optimism degree of the supervisor. A new Group Decision Support System (GDSS) is introduced by using this new methodology and applied in ranking eighteen national water resources projects. The group weights of the nine criteria were obtained by using the Extended OWA method with respect to the preferences of six stakeholders.

Keywords: Group decision support system, Integrated water resources management, Ordered weighted averaging, Consensus measure, Uncertainty

Introduction

Increasing competition among stakeholders for the limited water resources and the relative absence of the new and cheaper water resources have arised the need for using improved decision making models. Besides technical functions, decision making on alternative water resources projects is generally based on the fundamental and traditional objective of cost minimization. There is, however, a need to consider environmental and social implications as well, which can be done by using Multi-Criteria Decision Making (MCDM) techniques. Constructing a MCDM model needs to obtain the criteria and their relative importance. The weights of the criteria could be obtained by Group Decision Making (GDM) methods. Group decision support systems (GDSS) are introduced to solve these models simultaneously in an interactive environment. The main advantages of such GDSSs for water resources management are:

- To cope with limited water, financial and human resources;
- To allow for MCDM methods instead of single criterion decision-making;
- To avoid opportunity costs of delay in decision-making;
- To resolve conflict among stakeholders; and
- To simplify the administration of the projects.

GDSSs have been developed since the 1980s to help modeling semi-structured and unstructured decision problems based on the interaction with the stakeholders. Hipel et al. (1997) introduced GMCR II for conflict resolution. This GDSS is used for studying strategic conflicts that could arise in environmental management and also elsewhere. Theissen et al. (1998) developed ICANS helping all parties to identify feasible alternatives, if any exist, that should be preferred to each party's proposal. If such alternatives do not exist, then the program can help them to develop counter proposals. WINPRE was developed by Hämäläinen et al. (2001) to provide implementations of preference programming methods. Chen et al. (2004) introduced WARMF which calculates various combinations of point and non-point loads that can meet specific water quality criteria. Consensus module of this GDSS allows the stakeholders to formulate, evaluate, modify, and vote for alternatives. It also helps them to explore and evaluate the possible decision measures.

Although Yager (1988) pointed out that the attitudinal characteristics (risk acceptance/ aversion) of the DM has significant effect on the results of the MCDM problem, although most of the existing GDSS has not given explicit attention to these characteristics. This study introduces a new GDSS to overcome this inefficiency by using the OWA method.

The paper is organized as follows. A real case study is first described to justify the need for a GDSS. Then an Extended OWA is applied to aggregate the preferences of a group of DMs. This aggregation is the main step of the methodology and we will present it in detail. A new measure is developed to quantify consensus among the stakeholders. In addition sensitivity analysis on the weights of the criteria is finally performed by using a new method. Based on the results of this step, the 18 national water projects are ranked by using TOPSIS methodology. The entire methodology has been implemented by a software, entitled GFDM (Group Fuzzy Decision Making).

1. Case study: Decision making on water resources projects in Iran

Success of any GDSS in real applications depends on the collaboration among the stakeholders. For this reason we evaluated the present decision making process on water projects in Iran. To do this job, we considered three scenarios as follows:

1. The decision making process on water projects is now well established among the stakeholders and it does not need new decision making models.
2. The decision making process is not established but it can be improved by new tools such as group decision making models.
3. Since there is a high conflict among the stakeholders the decision making process can not be improved with any new model.

To evaluate these Scenarios, the relevant documents were first reviewed and then several meetings with fourteen directors in the main stakeholder organizations were conducted. These directors were the minister and the vice minister of Energy (responsible for water affairs), previous director of the water section of Iran's Management and Planning Organization (MPO), a parliamentarian, vice directors of the Water Resources Management Company (WRMC), director of a regional water authority, directors of two consulting engineering companies, and independent experts from the university. Based on these meetings and interviews the following outcomes were obtained:

- There is a discrepancy among the stakeholders' preferences on the projects. Then the Scenario one is not acceptable.
- Several acts and plans have been co-signed by the stakeholders in recent years, so suitable consensus-based decision making models could improve the present process. Thus Scenario three is not acceptable.
- Abuse of administrative power by some stakeholders has lead to wrong decisions. Consensus-based GDSSs are therefore required.
- The Government requires Integrated Water Resources Management (IWRM) in all decision makings processes. Stakeholder's participation, which is an important pillar of using IWRM, should be well considered in developing the GDSSs.

As a conclusion of these findings, Scenario two is the most accurate and so a consensus-based model could improve the decision making. After these face-to-face meetings, the decision making process on water resources projects was mapped in various flowcharts. One of them (the general process) is shown in Figure 1.

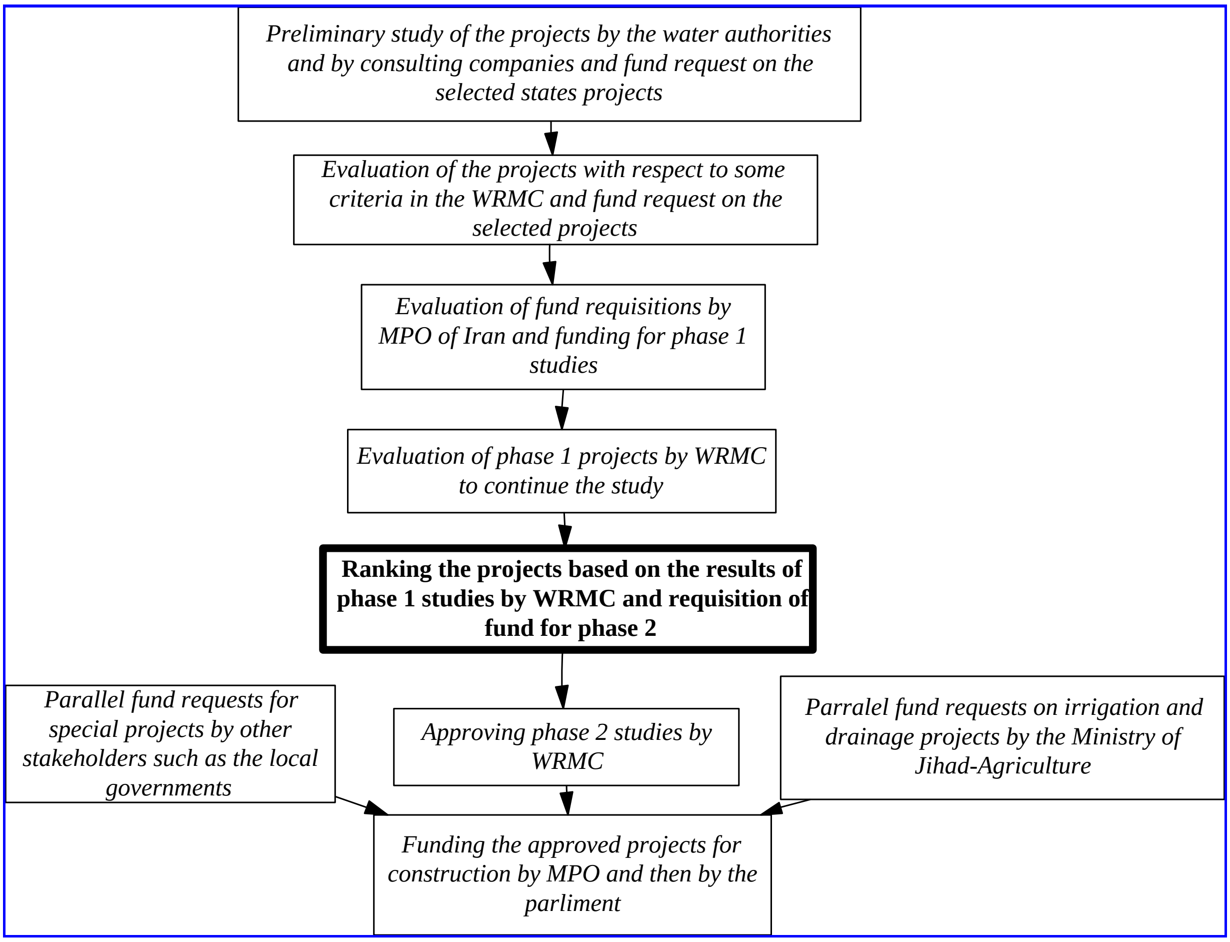

Fig. 1. General decision making process on the water resources projects in Iran

An important step in the decision making process is the ranking of the projects by the organization of WRMC (bolded box in Figure 1). The WRMC as the representative of the central Government was the client of this study. For its use we developed a GDSS, entitled GFDM. The GFDM includes a GDM module to obtain the consensus-based weights of the criteria, which will be used in the MCDM module.

2.1 The decision criteria and their importance

The GFDM needs to identify the criteria and their importance. Therefore, in the first step, similar plans of 20 countries were analyzed and screened, including Pakistan, Turkey, India, Kenya, Sweden, the United States and Brazil. Based on the state-of-the-art review and the national acts of Iran, preliminary criteria were next introduced (Zarghami et al., 2007). In order to revise and finalize the preliminary criteria, 30 experts conducted the revision. They participated in several sessions applying the Value Management methodology. These experts were selected from the Government, consulting companies, universities and Non-

Governmental Organizations (NGOs). The revised criteria according to the characteristics of the Sefidrud watershed were obtained as follows:

- Allocation of water to prior usages: How should water usages be prioritized? Water usages are domestic, industrial, agricultural, environmental and recreational. Their priority differs for each stakeholder due to its geographic, economic and social conditions.
- Number of beneficiaries: How many beneficiaries are influenced by the project? The number of the affected people is only counted, regardless of the water usage type.
- Supporting other projects: How important is the fact that the project may support and complement other projects (under operation/construction) in the region?
- Benefit/Cost: How important is the financial efficiency of the projects? The Benefit/Cost criterion is selected to measure efficiency.
- Range of environmental impacts: According to the environmental impact assessment studies, a group of experts supplied the range of the environmental impacts of each project in linguistic terms. These impacts have been assumed to be negative.
- Public participation: Water projects create social conflicts in the region. If the people have higher participation in the decision concerning their relocation, selling their lands, labour supply and regulating their water rights, then the project has larger chance to be successful. How important is this criterion?
- Developing willingness to settle in the border areas: How important is the fact that the project attracts people to settle in the border areas of the country?
- Controlling water outflow: The volume of controlled water outflow to the sea or to transboundary rivers and lakes.
- Job creation: How important is job creation and potential employment opportunities created by the project? Its importance varies for stakeholders due to their different rates of unemployment.

A board of DMs was formed including representatives of the five adjunct sections of the WRMC and an expert from MPO. Certain power was delegated to each decision maker which is shown in Table 1. After describing the criteria to the DMs, they presented their preferences (weights) by linguistic variables as shown in Table 1. The possible preferences were: very high (VH), high (H), slightly high (SH), medium (M), slightly low (SL), low (L) and very low (VL).

Table 1. Preferences of the DMs on the criteria

		DMs (Power of DM)					
No.	Criteria	DM_1(H)	DM_2(H)	DM_3(SH)	DM_4(SH)	DM_5(M)	DM_6(M)
1	Allocation of water to prior usages	H	SH	H	VH	H	SH
2	Number of beneficiaries	H	H	SH	SH	M	SH
3	Supporting other projects	VH	SH	VH	H	SH	H
4	Benefit/Cost	SL	VH	VH	VH	VH	SH
5	Range of negative environmental impacts	M	SH	VH	SL	H	SH
6	Public participation	VH	M	SH	SH	H	H
7	Developing willingness to settle in the border areas	SH	VH	M	M	SH	VH
8	Controlling water outflow	SH	VH	VH	SH	SH	H
9	Job creation	M	SH	SH	SH	H	SH

3. Group decision making methodology

Successful applications of OWA in GDM problems (Kacprzyk et al. 1992, Herrera et al. 1996, Bordogna et al. 1997, Ben-Arieh and Chen 2004, Choudhury et al. 2006, Pasi and Yager 2006, and other works) motivated us to use it in the GDM module of GFDM. OWA as an aggregation operator was initiated by Yager (1988) and has been applied in many fields including GDM. An *n*-dimensional OWA operator is a mapping $F: I^n \mapsto I$, where *I*= [0, 1], that has an associated *n*-dimensional vector $w = (w_1, w_2, ..., w_n)$ of order weights with $w_j \geq 0$ for all *j* and $\sum_{j=1}^{n} w_j = 1$, if it is defined as follows:

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

where b_j is the *j* th largest element of the set of the aggregated objects $\{a_1, a_2, ..., a_n\}$ and *n* is the number of the inputs. Notice that the components of the input vector have been ordered before multiplying them by the order weights. As an important characteristic of the OWA, it has a large variety in representing other aggregation operators by the different selections of the order weights. The order weights depend on the optimism degree of the client (Yager, 2002). Greater weights at the beginning of the vector indicate higher optimism degree (risk acceptance). Yager (1988) has defined the optimism degree (well known as Orness degree), *θ*, as:

$$\theta = \frac{1}{n-1}\sum_{j=1}^{n}(n-j)w_j \quad . \tag{2}$$

The well-known OWA method is next extended in three steps to model the group

MCDM problem in solving the GFDM:

Step 1: Since the inputs for applying OWA should be numerical values, it is necessary to convert the linguistic inputs of the decision matrix (e.g. the data in Table 1) to real numbers of the unit interval [0, 1]. Linguistic numbers can be modeled by using equivalent triangular fuzzy numbers as shown in Figure 2 and presented in Table 2. They can then be defuzzified by using the max-membership method.

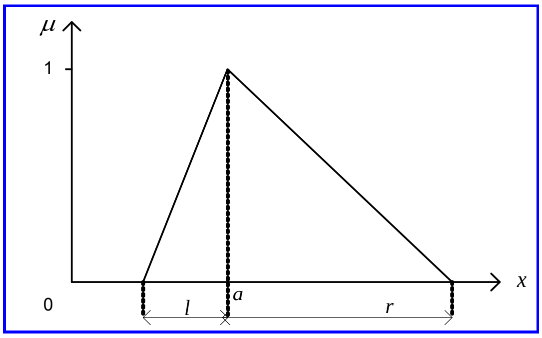

Fig. 2. A triangular fuzzy number *(a, l, r)*

Table 2. Linguistic variables and equivalent triangular fuzzy numbers

Linguistic variables	Triangular fuzzy numbers
Very Low	(0.00, 0.00, 0.10)
Low	(0.20, 0.10, 0.20)
Slightly Low	(0.35, 0.20, 0.20)
Medium	(0.50, 0.20, 0.20)
Slightly High	(0.65, 0.20, 0.20)
High	(0.80, 0.20, 0.10)
Very High	(1.00, 0.10, 0.00)

Step 2: OWA assumes identical importances for all inputs. However in this case study, the DMs had different powers (u_j). Therefore it was necessary to multiply the preferences of the DMs by their importance weights. The Extended OWA was then applied to the GDM problem. If the numerical value of the preference of DM_j on criterion i is denoted by $P_j(C_i)$, then the group preference of this criterion could be calculated by using the Extended OWA operator:

$$GP(C_i) = F(u_1P_1(C_i), u_2P_2(C_i), ..., u_nP_n(C_i)) \tag{3}$$

where u_j denotes the power weight of DM_j. In order to use this equation the order weights were needed, which could be obtained from the linguistic quantifiers (Yager, 1988):

$$w_j = Q(\frac{j}{n}) - Q(\frac{j-1}{n}), \quad j = 1, 2, ..., n. \tag{4}$$

In this study the particular form of Q has been chosen as $Q(r) = r^{\alpha}$ with a positive parameter α. For this type of *Q*, Malczewski (2006) has defined seven linguistic quantifiers to aggregate the *n* inputs. They are shown in Table 3. Using the order weights (4) and letting $n \to \infty$, the optimism degree could be calculated as:

$$\theta = \int_0^1 Q(r)dr = \int_0^1 r^{\alpha} dr = \frac{1}{1+\alpha} \ . \tag{5}$$

The client was then questioned according to the linguistic quantifiers of Table 3. If it wanted to include preferences of more people in the GDM problem then he was considered to be more pessimistic.

Table 3. Equivalent optimism degrees for linguistic quantifiers in combining the opinions

Linguistic quantifiers	optimism degree, θ
At least one of them	0.999
Few of them	0.909
Some of them	0.667
Half of them	0.500
Many of them	0.333
Most of them	0.091
All of them	0.001

In this case study, the client selected to include preferences of 'many' of the DMs in the final aggregated opinion. According to Table 3, the optimism degree is assumed to be 0.333. Then, by using (4) and (5), the order weights become (0.047, 0.095, 0.143, 0.190, 0.238, and 0.286), with *n* being the number of DMs (n=6).

Step 3: By applying the order weights, we obtained the group opinion, $GP(C_i)$ on the weight of each criterion *i* as shown in Figure 3 by crisp values. 'Benefit/cost' criterion had the highest importance weight.

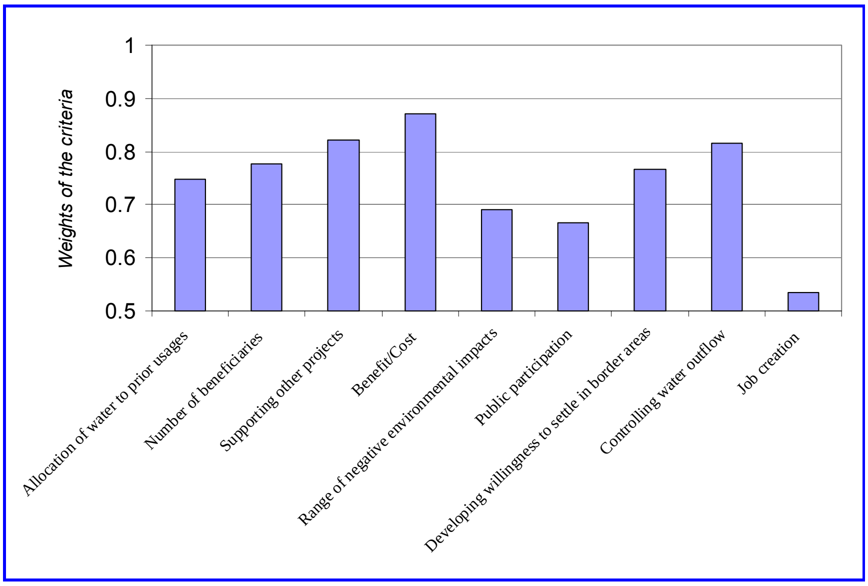

Fig. 3. Group weights of the criteria

The 'Benefit/cost' criterion had the highest weight and the 'Job creation' and 'Public participation' criteria showed the lowest weights.

Due to the possible discrepancy among the DMs, it was very important to have consensus on the values of the aggregated preferences before using them in solving the MCDM problem. In the next section a new consensus model will be introduced.

1 Consensus measure

The consensus measure among the DMs on the weight of the criterion *i* is defined as:

$$CGP(C_i) = 1 - \frac{1}{n}\sum_{j=1}^{n}\left|P_j(C_i) - GP(C_i)\right|^{\beta} \tag{6}$$

Where:

$CGP(C_i)$ is the consensus measure on criterion *i*;
$GP(C_i)$ is the numerical value of the group opinion on criterion *i*;
$P_j(C_i)$ is the numerical value of the opinion of DM_j on criterion *i*;
β is a parameter declaring the importance of differences;
n is the number of DMs.

Consensus on each criterion has been calculated and the results are shown in Figure 4 by selecting β=1. Based on Figure 4, the weights of the criteria 'allocation water to prior usages' and 'supporting other projects' have the highest consensus among the six DMs.

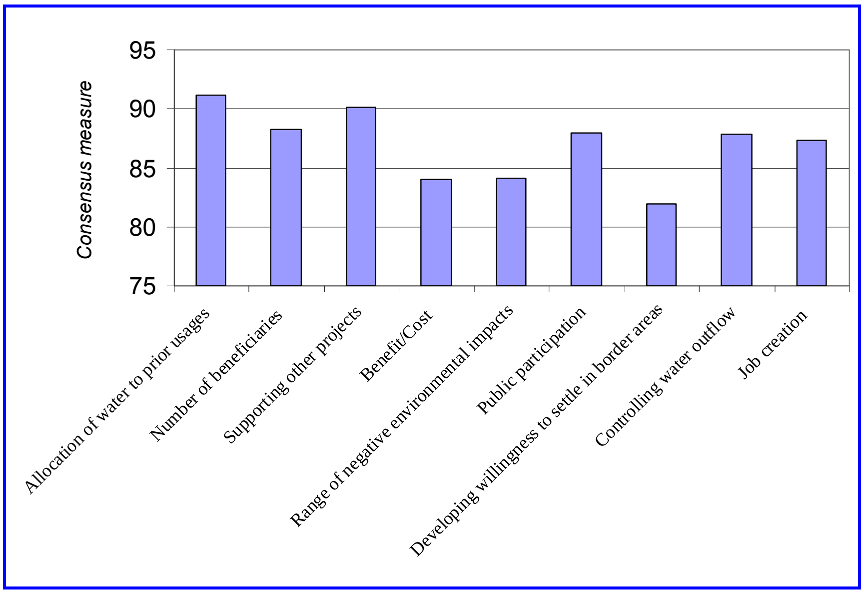

Fig. 4. Consensus measure $CGP(C_i)$ of the weight of each criterion

The approval of the consensus depends on a certain threshold obtained from the client. If a criterion has a lower consensus measure than the threshold, then it becomes necessary for the supervisor to negotiate with the members of the group for possible revisions in their individual preferences and recalculate the consensus measure. It is an iterative process and the GDM module of GFDM helps us to achieve this goal.

2 Sensitivity analysis

Water resources projects always include risks and the optimism degrees of the supervisors often change depending on the actual situations. The weights of the criteria shown in Figure 3 are based on a specific optimism degree and it is important to evaluate the effect of a change in the optimism degree to see the robustness of the weights. From equation (5) it is clear that $\alpha = 1/\theta - 1$ and by combining equations (4) and (1), we have the following expression for the combined weights of the criteria:

$$F = \sum_{j=1}^{n} \left[(\frac{j}{n})^{\frac{1}{\theta}-1} - (\frac{j-1}{n})^{\frac{1}{\theta}-1} \right] b_j \ . \quad (7)$$

The sensitivity of *F* with respect to the optimism degree is obtained by differentiation:

$$S = \frac{\partial F}{\partial \theta} = \frac{-1}{\theta^2} \left[(\frac{1}{n})^{\frac{1}{\theta}-1} \ln(\frac{1}{n}) b_1 + \sum_{j=2}^{n-1} [(\frac{j}{n})^{\frac{1}{\theta}-1} \ln(\frac{j}{n}) - (\frac{j-1}{n})^{\frac{1}{\theta}-1} \ln(\frac{j-1}{n})] b_j - (\frac{n-1}{n})^{\frac{1}{\theta}-1} \ln(\frac{n-1}{n}) b_n \right] , \quad (8)$$

where S is the sensitivity measure of *F* by changing the optimism degree *θ*. The sensitivity measures of the nine criteria have been calculated and the results are shown in Figure 5.

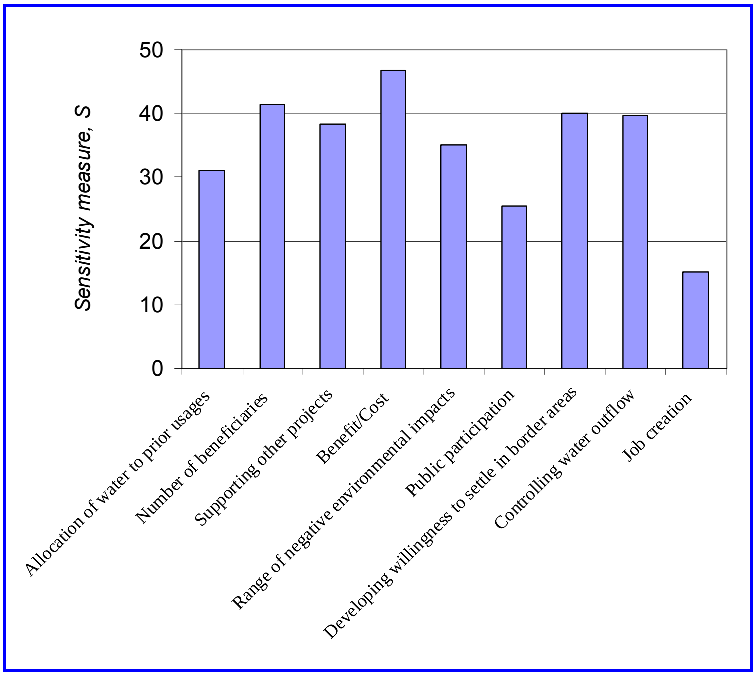

Fig. 5. Sensitivity measures of the criteria

The results presented in Figure 5 show that in the case of any change in the optimism degree, the scores of the criterion 'job creation' will become less sensitive than others, while 'benefit/cost' is the most sensitive one.

Group Decision Support System, GFDM

The decision making process has to be repeated by an interactive process with the decision makers until a satisfactory solution is obtained. It is however hard to achieve the final results. For example, the uncertainty in input data either in group preferences or in the evaluation of the projects may result in time-consuming calculations. In order to overcome this difficulty we prepared GFDM, which is the enhanced version of FDM (Zarghami et al. 2007). The original version of FDM had only the MCDM module without GDM. GFDM combines the preferences of the DMs on the criteria and calculates the weights of the criteria and the consensus measures of the criteria. After obtaining the consensus-based criteria, GFDM applies them in the MCDM process. The MCDM module embodies an expert system whose duty is to choose appropriate methods from SAW, fuzzy SAW, TOPSIS or fuzzy TOPSIS based on the structure of the problem. Their methodology is presented in Appendix 1. These methods are selected according to the comparative and review studies of Chen and Hwang (1991) and Triantaphyllou and Lin (1996). The fuzzy arithmetic is also described in Appendix 2.

The corresponding rules used in the expert system of the MCDM module are chosen depending on the number of criteria, the number of alternatives, and the type of the evaluations in the decision matrix. The rules of the expert system are as follows:

- If all of the evaluations in the decision matrix are crisp, GFDM does not use the fuzzy logic. It will use TOPSIS or SAW, instead.
- If the number of alternatives with respect to the number of criteria is less than half then either SAW or fuzzy SAW will be selected, otherwise GFDM uses TOPSIS or Fuzzy TOPSIS.

In the MCDM module, the evaluations of the alternatives versus criteria can be numerical, triangular fuzzy, trapezoidal fuzzy or linguistic variables. The importance weights of the criteria can also be considered as linguistic variables or crisp numbers. GFDM transforms linguistic and crisp variables to positive triangular fuzzy numbers as shown in Table 2. After calculating the combined goodness measure for each alternative, their fuzzy measures will be defuzzified to be compared with each other. The defuzzification has been done before computing the square root, as needed in the equations of the TOPSIS method.

Ranking national water resources projects by GFDM

There are eighteen water resources projects under study associated to several state-wide water authorities in Iran. Concerning their limited financial budget and time restrictions, WRMC requested the ranking of these projects in order to schedule their construction. These projects are reservoirs with attached water distribution networks. Their decision matrix is shown in Table 4. The evaluations of these projects with respect to the nine criteria were obtained from the corresponding authorities and then their data were approved by the client. According to the Table 4, the evaluations were done by both linguistic numbers and triangular fuzzy numbers.

Table 4. Evaluations matrix for some of the water resources projects under study in Iran

Projects	Allocation of water to prior usages	Number of beneficiaries	Supporting other projects	Benefit/Cost	Range of negative environmental impacts	Public participation	Developing willingness to settle in the border areas	Controlling water outflow	Job creation
	Weights of the criteria (according to the results of GDM model)								
	0.75	0.78	0.82	0.87	0.69	0.67	0.77	0.82	0.54
1 Kor	SL	SL	L	(1.2, 0.1, 0.1)	VL	VL	VH	(65, 5, 5)	M
2 Shor	SH	M	H	(1.2, 0.1, 0.1)	L	VL	VL	(0,0,0)	VH
3 Kasilian	H	VH	H	(3.4, 0.3, 0.3)	L	VL	VL	(160, 10, 10)	VH
4 Darian	H	VH	H	(1.0, 0.0, 0.0)	L	L	VH	(2810, 100, 10)	VH
5 Azad	SH	VH	H	(1.0, 0.0, 0.0)	L	L	VH	(2240, 100, 10)	VH
6 Zanganlo	SH	VL	VL	(1.0, 0.0, 0.0)	VL	H	VH	(30, 5, 5)	VH
7 Shirinab	SH	L	SH	(1.1, 0.1, 0.1)	VL	M	VL	(0,0,0)	SH
8 Sardasht	SH	VL	H	(1.1, 0.1, 0.1)	VL	SH	VL	(0,0,0)	H
9 Seidon	SH	L	M	(1.0, 0.0, 0.0)	L	M	VL	(0,0,0)	M
10 Ajorlo	SL	H	H	(1.5, 0.1, 0.1)	L	H	M	(0,0,0)	VH
11 Khanegoli	L	M	H	(0.9, 0.1, 0.1)	L	M	VL	(0,0,0)	VH
12 Ghazan	SL	H	H	(1.1, 0.1, 0.1)	VL	VH	M	(135, 10, 10)	VH
13 Fishel	H	M	H	(2.1, 0.2, 0.2)	VL	H	M	(15, 2, 2)	VH
14 Emarat	SL	H	H	(1.1, 0.1, 0.1)	VL	H	VH	(450, 50, 50)	VH
15 Khalesan	SL	SH	SH	(1.7, 0.1, 0.1)	L	M	VL	(0,0,0)	M
16 Kharmangah	SL	SH	SL	(1.7, 0.1, 0.1)	VL	M	VL	(0,0,0)	SL
17 Divrash	H	SH	L	(2.7, 0.2, 0.2)	VL	M	VL	(0,0,0)	SL
18 Aziz kian	SL	SH	SH	(2.0, 0.2, 0.2)	VL	VL	VL	(0,0,0)	SL

The combined goodness measure of any project could be finally calculated by using GFDM. The final results for ranking the projects are shown in Figure 6, respectively. Since there were nine criteria and eighteen alternatives in the decision matrix and also the evaluations were not numerical, the expert system of the GFDM used the fuzzy TOPSIS method for solving the MCDM problem.

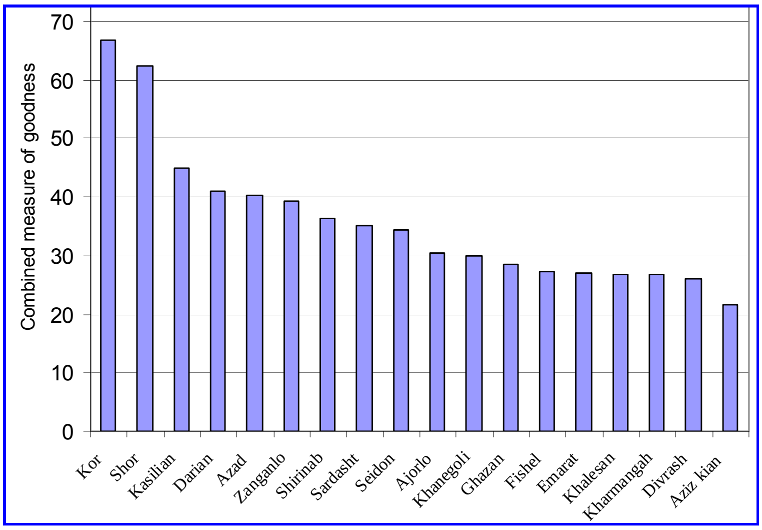

Fig. 6. Combined goodness measure of the national water resources projects

According to Figure 6, The 'Kor' is the most preferred project while the 'Shor' and 'Kasilian' are ranked second and third. However 'Aziz kian' is the least preferred project. The combined goodness measures of some projects are very close to each other which could be resolved by using more precise input data for their evaluations with respect to the criteria.

Conclusions

Introducing an effective and applicable GDDS was the main contribution of this paper for ranking water resources management in a nationwide scale. An extended version of the OWA operator successfully obtained the group weights of the criteria. A quantified consensus measure has been also introduced which allowed the client for conducting additional negotiations, if necessary, using the user-friendly modules of the GFDM. A new sensitivity analysis model was developed to evaluate the robustness of the criteria weights to changes in the optimism degree of the client. Fuzzy MCDM tools were applied in GFDM for ranking water resources projects with uncertain evaluations with respect to the criteria. Interactions between the client, the DMs and the stakeholders during the GFDM process resulted in satisfactory decision outcomes. Similar procedure can be used in solving other problems and obtain better decisions.

Appendix 1

A.1. Simple Additive Weighting (SAW) method

Suppose the evaluations of some alternatives with respect to certain criteria are known in the form of a decision matrix $D[X_{ij}]$, (*i* =1, 2,. . , *m*; *j*=1,2, . . . ,*n*).

Step 1: Transform the numerical evaluations into non-dimensional units to allow their comparisons. In this study the unit-less evaluations were obtained as

$r_{ij} = \frac{X_{ij}}{Max_i(X)}$, for maximized criterion; (9)

$r_{ij} = \frac{Min_i(X)}{X_{ij}}$, for minimized criterion. (10)

Step 2: Obtain a set of weights u_j (*j*=1,2*, . .,n),* from the client for each criterion and calculate the weighted-normalized decision matrix *V* by multiplying each column of matrix *R* by its associated weight u_j:

$V = [u_j \bullet r_{ij}]$, (*i*=1,2, . .,*m; j*=1,2, . .,*n).* (11)

Step 3: Calculate the combined goodness measure for each alternative:

$S_i = \sum_{j=1}^{n} u_j \bullet r_{ij}$. (12)

Step 4: Rank the alternatives in descending order of S_i.

A.2. Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method

TOPSIS is based on the concept that the chosen alternative should have the shortest distance from the ideal solution and the longest from the negative ideal solution (Hwang and Yoon, 1981). Assume that all alternatives have monotonically increasing (or decreasing) utility; then it is easy to locate the ideal solution which is a combination of all best criterion values, and the negative ideal solution is a combination of all worst criterion values. One approach is to take the alternative that has the minimum (weighted) Euclidean distance from the ideal solution in a geometrical sense. The computation structure of the TOPSIS method consists of the following steps:

Step 1: Follow the step 1 of the SAW method.

Step 2: Follow the step 2 of the SAW method.

Step 3: Determine the ideal solution A^* and negative ideal solution A^- from matrix *V* as follows:

$$A^* = \left\{ \left(\max_i v_{ij} \mid j \in J \right); \left(\min_i v_{ij} \mid j \in J' \right) \middle| i = 1,2,..,m \right\} = \left\{ v_1^*, v_2^*, .., v_j^*, .., v_n^* \right\} \quad (13)$$

$$A^- = \left\{ \left(\min_i v_{ij} \mid j \in J \right); \left(\max_i v_{ij} \mid j \in J' \right) \middle| i = 1,2,..,m \right\} = \left\{ v_1^-, v_2^-, .., v_j^-, .., v_n^- \right\} , \quad (14)$$

Where J is associated with benefit criteria and J' is associated with cost criteria. Notice that A^* and A^- are not absolute values but they represent the best or worst evaluation among the different alternatives analyzed in matrix V.

Step 4: Compute the distance of each alternative from the positive ideal solution:

$$S_{i^*} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, \quad for \quad i = 1,2,..,m \tag{15}$$

and the distance of each alternative from the negative ideal solution:

$$S_{i-} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \quad for \quad i = 1,2,..,m \tag{16}$$

Step 5: Compute the relative combined goodness measure for each alternative A_i with respect to A^* as:

$$C_{i^*} = \frac{S_{i-}}{S_{i^*} + S_{i-}} \quad , \quad i = 1,2,...,m \tag{17}$$

Notice that $0 \le C_{i^*} \le 1$, and C_{i^*} =1 if $A_i = A^*$, and C_{i^*} = 0 if $A_i = A^-$. Larger values of C_{i^*} indicate that alternative A_i is close to A^*.

Step 6: Rank the alternatives in descending order of C_{i^*}.

Appendix 2

Let $P = (a_1, l_1, r_1)$ and $Q = (a_2, l_2, r_2)$ be two positive triangular fuzzy numbers. Then the initial fuzzy arithmetic operations are as follows (Bonissone, 1982):

$$P + Q = (a_1 + a_2, l_1 + l_2, r_1 + r_2) \tag{18}$$

$$P - Q = (a_1 - a_2, l_1 + r_2, r_1 + l_2) \tag{19}$$

$$P \cdot Q = (a_1 a_2, a_1 l_2 + a_2 l_1 - l_1 l_2, a_1 r_2 + a_2 r_1 + r_1 r_2) \tag{20}$$

$$P \div Q = \left(\frac{a_1}{a_2}, \frac{a_1 r_2 + l_1 a_2}{a_2 (a_2 + r_2)}, \frac{a_1 l_2 + r_1 a_2}{a_2 (a_2 - l_2)} \right) \tag{21}$$

Following the steps of the SAW or the TOPSIS method in the case of fuzzy variables, the arithmetic operations (18-21) are used in equations (9-14).

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