Effective Water Governance by Using Group Decision Support Systems; Case Study of Lake Urmia, Iran

Mahdi Zarghami, PhD

Faculty of Civil Engineering, University of Tabriz, Tabriz, Iran, zarghaami@gmail.com

Abstract:

Limited water resources with uneven distribution in addition to the growing demands are the main challenges of the water governance in Iran. The Government has planned several water resources development project and due to their complex technical, socio-economical, and environmental outcomes, comprehensive evaluation is needed. To select more adaptive and accountable projects, suitable group decision support systems are also required. In this research four proposed routes of water transfer schemes to the critical drying Lake Urmia in Iran are evaluated with respect to the different criteria. The criteria and their weights are obtained from an organization that is responsible for major water infrastructures in the basin. By using efficient group multi-criteria decision making method, the four alternatives are ranked and the most robust water transfer route is selected. Results show the importance of using decision support systems to provide participatory and effective governance on water infrastructures.

Key words: Water infrastructures, good governance, participatory decision making, Lake Urmia.

1. Introduction

Decision making on alternative water resources projects is traditionally based on the sole objective of cost effectiveness. Increasing competition among stakeholders and the relative absence of the new and cheaper water resources have arised the attention of lawyers, economists and engineers to the different aspects of the water governance as described in Biermann et al. (2009). There is, however, a need to consider environmental and social externalities as well, which can be done by using group decision support systems (GDSS) in an interactive environment. These models have been more developed in recent years especially by the works of Hipel et al. (1997), Thiessen et al. (1998), Hämäläinen et al. (2001), Chen et al. (2004) and Zarghami et al (2008a). Using any GDSS is however related exactly to the case and it is not suggested to use a specific GDSS in every problem.

In this paper, to develop an effective GDSS, we first evaluated the governance on water resources development projects in Iran. To understand and monitor the present situation, firstly, the relevant documents were reviewed and then several meetings with fourteen directors in the main stakeholder organizations were conducted. These directors (in year 2005) were the minister and the vice minister of Energy (responsible for water affairs), former 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.

- 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.
- 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). Stakeholders' participation, which is an important pillar of using IWRM, should be well considered in developing the GDSSs.

As a conclusion of these findings, a consensus-based model could improve the present decision making. After these face-to-face meetings, the decision making process on water projects was mapped in various flowcharts. One of them (the general process) is shown in Figure 1. An important step in the decision making process is the ranking of the projects by WRMC (bolded box in Figure 1).

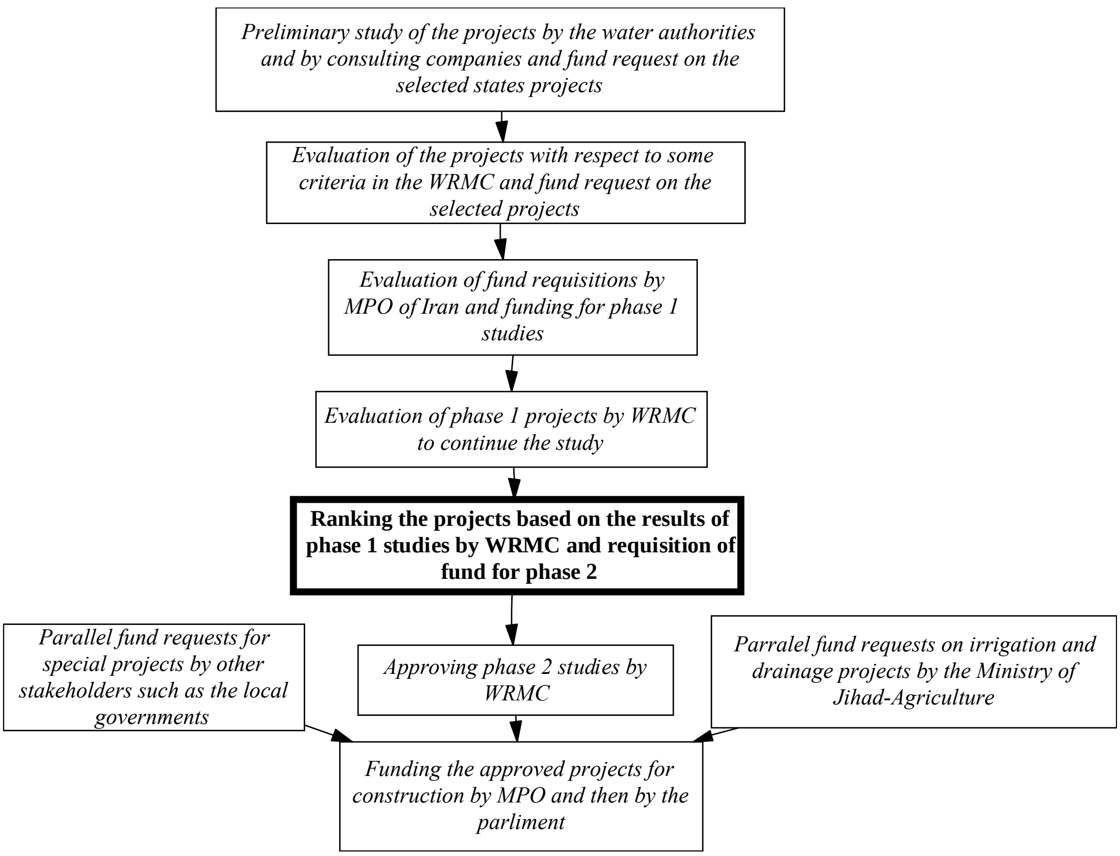

Figure 1. General decision making process on the water projects in Iran

This paper develops a GDSS and then uses it in selecting an alternative from four inter-basin water transfer projects to maintain the drying Lake Urmia in Iran (Figure 3). The WRMC agent in the East Azerbaijan province is the main client of this study. The client has represented three decision makers (DMs) as representatives of the stakeholders and their performances will be used in computing group preferences on criteria. The paper is organized as follows. First the mathematical methodology used in the GDSS is described. Then it will be applied on the real case study of Lake Urmia and the results of application will be presented. Then the paper concludes the study.

2. Methodology

The methodology of GDSS used in this study consists of two main sections: first the group preferences on the effective criteria and their relative weights are evaluated by fuzzy set theory. Then the decision alternatives are evaluated and then ranked by using a successful multi-criteria decision analysis (MCDA) entitled Compromise Programming (Zeleny, 1976).

2.1 Group decision making by using fuzzy set theory

In many problems, human judgments are often vague and cannot be expressed as an exact numerical value. Such vague judgments are frequently required to evaluate water resources projects and it is recommended to use the fuzzy set theory in tackling their uncertainty (Simonovic, 2009). Fuzzy sets are the means of representing and manipulating the data that are not precise, but rather vague. Let X be a nonempty set. A fuzzy set A in X is described by its membership function μ_A: $X \rightarrow [0, 1]$ and $\mu_A(x)$ is interpreted as the degree of association of element x in fuzzy set A for each $x \varepsilon X$.

Definition 1. The degree that a value of x belongs to either sets A or B is the maximum of the two individual membership function values defined as

$$\mu_{A\cup B}(x) = \text{maximum}(\mu_A(x), \mu_B(x)). \tag{1}$$

Definition 2. The degree that a value of a variable x is simultaneously in both sets A and B is the minimum of the two individual membership function values defined as

$$\mu_{A\cap B}(x) = \text{minimum}(\mu_A(x), \mu_B(x)). \tag{2}$$

A fuzzy number A is also a fuzzy set of the real line with a normal, convex and continuous membership function of bounded support.

Definition 3. The trapezoidal fuzzy number is defined with tolerance interval [a, b], left width l and right width r as shown in Figure 2. If $a = b$, then it becomes a triangular fuzzy number.

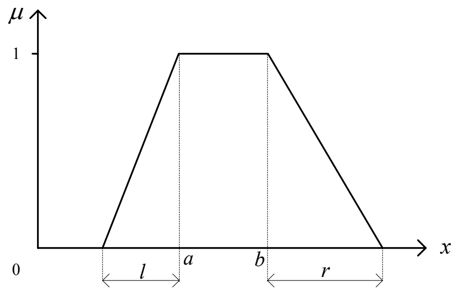

Figure 2. A trapezoidal fuzzy number $\mu_1 = (a_1, b_1, l_1, r_1)$

Let $\mu_1 = (a_1, b_1, l_1, r_1)$ and $\mu_2 = (a_2, b_2, l_2, r_2)$ to be any two positive trapezoidal fuzzy numbers. Then the initial arithmetic operations are as follows (Bonissone, 1982):

$$\mu_1 + \mu_2 = (a_1 + a_2, b_1 + b_2, l_1 + l_2, r_1 + r_2) \quad (3)$$
$$\mu_1 - \mu_2 = (a_1 - b_2, b_1 - a_2, l_1 + r_2, r_1 + l_2) \quad (4)$$
$$\mu_1 \times \mu_2 = (a_1 a_2, b_1 b_2, a_1 l_2 + a_2 l_1 - l_1 l_2, b_1 r_2 + b_2 r_1 + r_1 r_2) \quad (5)$$

$$\mu_1 \div \mu_2 = \left(\frac{a_1}{b_2}, \frac{a_2}{b_1}, \frac{a_1 r_2 + l_1 b_2}{b_2 (b_2 + r_2)}, \frac{b_1 l_2 + r_1 a_2}{a_2 (a_2 - l_2)} \right) \quad (6)$$

In this paper the uncertain preference on criteria are modeled with suitable fuzzy membership functions and then fuzzy arithmetic operations of (3-6) in any step of the process will give the group weights of the criteria. After obtaining the final group preferences, their fuzzy numbers should be compared together. To compare the fuzzy numbers several methods are known in the literature. The simplest way is to defuzzify them by the max-membership method, which selects the value(s) with highest membership degree. The second approach is by using the α-cuts. In this way the membership function is cut horizontally at a finite number of α–levels between 0 and 1. For each α-level of the membership function, the minimum and maximum possible values of the variable x could be determined. With a constant α value, the alternative with higher value of x will have better rank. Chen and Hwang (1991) gave a comprehensive state-of-the-art in using fuzzy set theory for decision making.

2.2 Compromise programming for MCDA problem

After obtaining the criteria and their relative weights we compare the decision alternatives with respect t the criteria. The compromise programming method is very popular in applications for water resources management (Zarghami et al. 2008 among others). There are two fundamentally different versions of the compromise programming method. In the first case the DM specifies (or we compute) the ideal point, the components of which are the subjective or computed best values of the different criteria. The ideal point is an n-dimensional vector, and the evaluation vector X_j of each alternative is compared to the ideal point by computing their distances. The alternative with the smallest distance is considered the best. In the second approach the DM specifies (or we compute) the nadir, the component of which are the subjective or computed worst values of the criteria. The nadir also has n component, each alternative j will be compared to the nadir by computing the distance of the evaluation vector X_j from the nadir. The alternative with the largest distance is selected as the best choice. In order to avoid the difficulties resulting from the different units of the criteria, in this method all criteria are normalized, so the components of the ideal point, the nadir and the evaluation vectors are all normalized. In most applications the weighted Minkowski-distance is used. Let a_i^* denote the i^{th} component of the ideal point and a_{i*} the i^{th} component of the nadir, and assume that linear transformation is used for normalizing. Then the distance of alternative j from the ideal point is given by

$$D_j^p = \left\{ \sum_{i=1}^{n} (w_i \frac{a_i^* - a_{ij}}{a_i^* - a_{i*}})^p \right\}^{\frac{1}{p}} \quad (7)$$

where $p \geq 1$ is a positive user-selected model parameter. Similarly the distance of alterative j from the nadir is defined by relation

$$d_j^p = \left\{ \sum_{i=1}^{n} (w_i \frac{a_{ij} - a_{i*}}{a_i^* - a_{i*}})^p \right\}^{\frac{1}{p}} . \qquad (8)$$

The selection of parameter p is very important, since it has a significant effect on the final choice. The case of p=1 corresponds to simple average, p=2 to squared averaging, and $p=\infty$ is selected if only the largest deviation is considered. Tecle et al (1988) describes that "Varying the parameter p from 1 to infinity, allows one to move from minimizing the sum of individual regrets (i.e., having a perfect compensation among the objectives) to minimizing the maximum regret (i.e., having no compensation among the objectives) in the decision making process. The choice of a particular value of this compensation parameter p depends on the type of problem and desired solution. In general, the greater the conflict between players, the smaller the possible compensation becomes". In the case of equation (7) we should minimize the distance from the ideal point and in the case of equation (8) we should maximize distance from nadir.

3. Case Study

Lake Urmia in Northwestern Iran is the largest inland lake of the country and one of the largest saline lakes in the world (613 253 ha) (Figure 3). The lake is one of the most important and valuable aquatic ecosystems in the country. About 550 plant species, including unique Artemia Species have been recognized within its ecological zone. Because of its unique natural and ecological features the lake has been designated as National Park, Ramsar Site and a UNESCO Biosphere Reserve (CIWP, 2008).

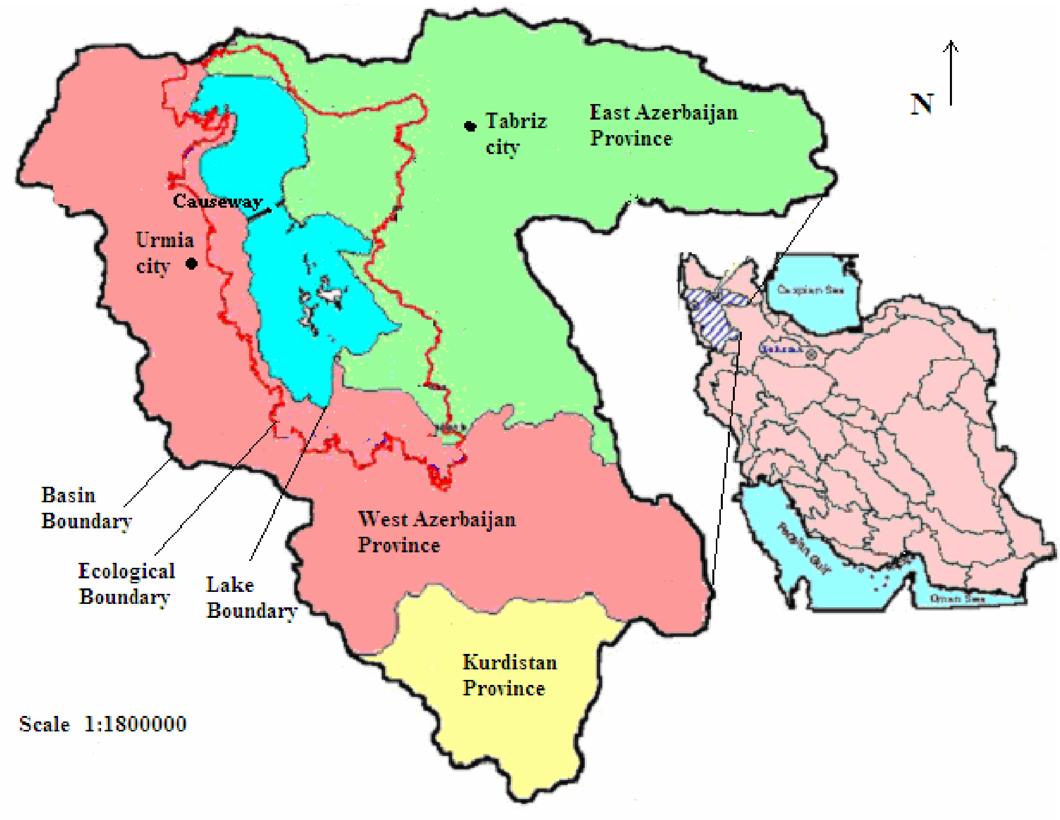

Figure 3. The position of the Lake Urmia basin

The lake basin, as a unique socio-ecological region, faces extreme water shortages in the recent years due to the poor water governance and also climate change. Because of the intense agricultural development and rapid urbanization, the groundwater level in some parts of basin is lowered upto 16 meters (Figure 4). According to the study of Alesheikh et al (2009) the area of Lake in 1998 and 2001 equaled to 5650 and 4610 square kilometers, respectively. Therefore, its area has been decreased about 1040 square kilometers from August 1998 to August 2001. The water level of lake is now less than about 5 meter of its average and also its critical level (Figure 5). The lake requires a minimum inflow of 3 billion cubic meters per year (CIWP, 2006) to compensate annual evaporation. These decreasing water levels are leading to an ecologic disaster in the near future.

In addition to former bad governance examples, a large highway project is constructed to facilitate transportation between the east and west cities of the lake. However the most rivers flow into the lake from the south, then the causeway has changed the normal circulating regime of the lake, resulting in many ecological problems.

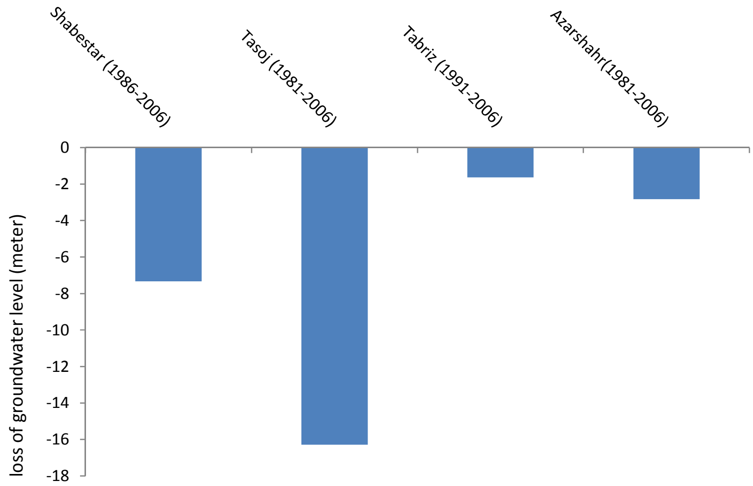

Figure 4. The groundwater level shortfall in some sub-basins of the Lake Urmia (in years?)

Vekerdy (2009) emphasizes that "Due to the intensive irrigation and pumping, the surface and the groundwater resources are overused around the lake. Less and less water is available for the compensation of evaporation in the Urmia Lake, so the shoreline retreats, leaving salt flats behind. This land cannot be used for agricultural production, but it can be a source of wind-blown salty dust, which precipitates on the agricultural lands and makes production impossible. The dust might cause severe respiratory diseases among the population in the basin, as was experienced in one of the largest environmental disasters of this kind, around the Aral Sea."

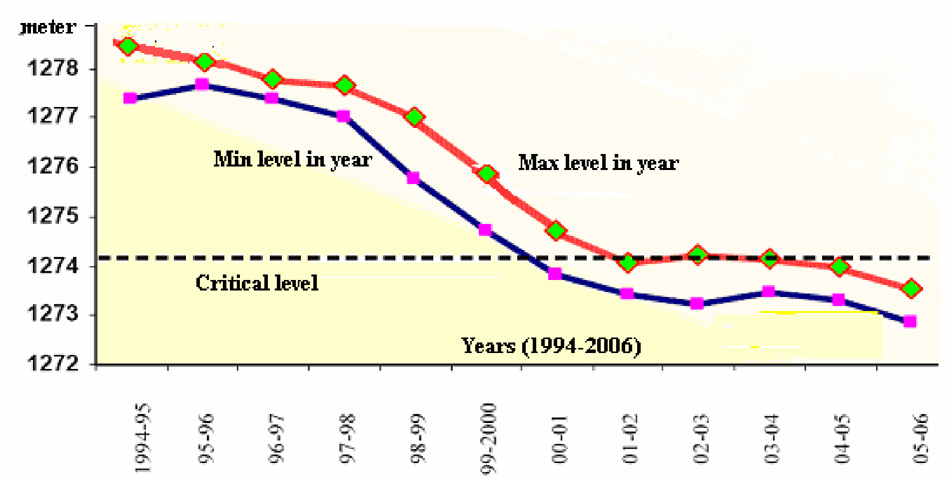

Figure 5. The annual sea level of Lake Urmia (modified from CIWP, 2008)

Long-term vision of the lake insists that it will have adequate water to sustain an attractive landscape and rich biodiversity where people and local communities can make wise use of its resources, and will enhance cooperation between the involved provincial organizations (CIWP, 2008). The local and national organizations have now plan to maintain this worse condition. One of them is by using inter-basin water transfer projects, which has been already successful in some cases (Ghassemi and White, 2007). Therefore several water transfer projects are proposed to partially conserve this drying lake. In one of these transfers, four different routes are defined and the aim of this study is to evaluate and then select the best route.

3.1 The effective criteria

To evaluate the projects we need first several effective criteria and their weights which are obtained by questioning three responsible DMs. The criteria are {negative environmental impacts, construction cost, simplicity of construction, and social acceptance}.

To obtain the group weights of these criteria, a board of DMs was formed and certain power was delegated to each DM by the client. After describing the criteria, DMs presented their preferences (weights) by using linguistic variables as shown in Table 1. The possible preferences were in the range of {very high, high, slightly high, medium, slightly low, low and very low}.

Table 1. The evaluation of the criteria by three DMs

		Criteria			
Decision makers	Power of DMs	C_1: Environmental impacts	C_2: Construction cost	C_3: Simplicity of construction	C_4: Social acceptance of the route
DM_1	High	High	Very High	Medium	Slightly Low
DM_2	Medium	Slightly High	Medium	High	High
DM_3	Slightly Low	Medium	Very High	Slightly Low	High

The linguistic variables of Table 1 are modeled with the fuzzy numbers as represented by Figure 6.

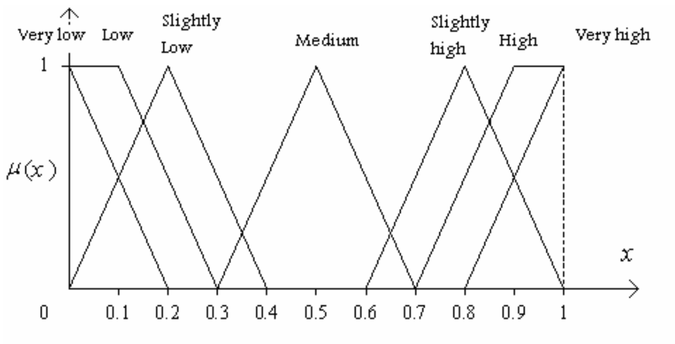

Figure 6. The equivalent fuzzy numbers of linguistic terms

Then by using the fuzzy simple additive weighting method and equations (7) and (9), we compute the fuzzy weight of criterion 1 as follows:

$$F_1 = \sum_{i=1}^{3} w_i a_{i1} = (\text{High*High})+(\text{Medium*Slightly High})+(\text{Slightly low*Medium})$$

=(0.9*0.9, 1*1, 0.9*0.2+0.9*0.2-0.2*0.2, 1.0*0.0+1.0*0.0+0.0*0.0)+(0.5*0.8, 0.5*0.8, 0.5*0.2+0.8*0.2-0.2*0.2, 0.5*0.2+0.8*0.2+0.2*0.2)+(0.2*0.5, 0.2*0.5, 0.2*0.2+0.5*0.2-0.2*0.2, 0.2*0.2+0.5*0.2+0.2*0.2)=(1.31, 1.50, 0.64, 0.48)

Similarly we have F_2=(1.35, 1.45, 0.70, 0.44), F_3=(0.94, 1.04, 0.52, 0.52), and also F_4=(0.81, 0.90, 0.60, 0.60). By using the max-membership method, the defuzzified criteria weights are 1.40, 1.40, 0.99, and 0.85 respectively. If we normalize the weight vector it becomes {0.30, 0.30, 0.21, 0.19}.

3.2 Ranking of the water transfer alternatives

Table 2 presents the evaluation matrix of four alternatives with respect to four criteria. These evaluations were obtained from the corresponding authorities and then their data were approved by the client. Now we use the compromise programming method to find the appropriate alternative.

Table 2. The evaluation matrix of alternatives with different criteria

Criteria	Weights of criteria	Alternatives			
		A_1	A_2	A_3	A_4
Environmental negative impacts (unitless between 0 and 1)	0.30	0.76	0.76	1.00	0.83
Construction cost (Millions US $)	0.30	211	190	161	168
Simplicity of construction (unitless between 0 and 1)	0.21	0.14	0.86	0.57	0.57
Social acceptance (unitless between 0 and 1)	0.19	0.57	0.43	0.29	0.86

In Table 2, the ideal point components are the maximum values for positive criteria, the components of the nadir are the actual minimum values and in reverse order we do for the negative criteria. So the ideal and nadir points are (0.76, 161, 0.86, 0.86) and (1.00, 211, 0.14, 29) respectively. Using the distance formula (8) with p=2 and the weights (w_1=0.3, w_2=0.3, w_3=0.21 and w_4=0.19) as before, the distances of four alternatives from nadir become

$$D_1^2=\left\{0.30^2(\frac{0.76-1.00}{0.76-1.00})^2+0.30^2(\frac{211-211}{161-211})^2+0.21^2(\frac{0.14-0.14}{0.86-0.14})^2+0.19^2(\frac{0.57-0.29}{0.86-0.29})^2\right\}^{\frac{1}{2}}\approx 0.31$$

$$D_2^2=\left\{0.30^2(\frac{0.76-1.00}{0.76-1.00})^2+0.30^2(\frac{190-211}{161-211})^2+0.21^2(\frac{0.86-0.14}{0.86-0.14})^2+0.19^2(\frac{0.43-0.29}{0.86-0.29})^2\right\}^{\frac{1}{2}}\approx 0.39$$

$$D_3^2=\left\{0.30^2(\frac{1.00-1.00}{0.76-1.00})^2+0.30^2(\frac{161-211}{161-211})^2+0.21^2(\frac{0.57-0.14}{0.86-0.14})^2+0.19^2(\frac{0.29-0.29}{0.86-0.29})^2\right\}^{\frac{1}{2}}\approx 0.33$$

$$D_4^2=\left\{0.30^2(\frac{0.83-1.00}{0.76-1.00})^2+0.30^2(\frac{168-211}{161-211})^2+0.21^2(\frac{0.57-0.14}{0.86-0.14})^2+0.19^2(\frac{0.86-0.29}{0.86-0.29})^2\right\}^{\frac{1}{2}}\approx 0.40$$

The A_4 has the largest distance from nadir, so it is the best choice. A_2 is the second most preferred alternative. The ranking of the alternatives can be also obtained by ordering them in decreasing D_j values. In this case

$$A_4 \succ A_2 \succ A_3 \succ A_1.$$

Notice that in the case of p=1, the results of using the compromise programming method and the simple additive weighting methods are equivalent to each other; they result in the same best choice and ranking of the alternatives as follows:

$$A_4 \succ A_2 \succ A_3 \succ A_1,$$

that the A_4 is again the best choice and the A_2 is the second most preferred one. In the case of using large values for p it converges to the max-max method. The max-max method selects the alternative which has the maximum value in the normalized evaluation matrix of the alternatives. The result of using compromise programming with p=10 is as follows:

$$A_2 \succ A_3 \succ A_1 \succ A_4.$$

In this case, the A_2 is the best and the A_4 is the least preferred decision. Comparing the results of these three Scenarios of p values, shows that the second alternative is most robust one if the p value is uncertain. In the case of the larger p values, which would be the case if DM has very pessimistic view about the risk of decision making, the second alternative is preferred. The fourth alternative is however has the highest combined goodness measure in the case of small p value, which represents a DM with neutral view on the risk.

4. Conclusion

Lake Urmia basin is under critical condition of its ecological and economical life. It is mainly due to rapid urbanization, unsustainable agricultural development and recent droughts probably caused by climate change. To modify the condition the Government plans to transform water from other basins. In this study, four alternative water transfer routes are evaluated using a GDSS and the study revealed the most reliable route with respect to the preferences of the different decision makers. According to this study, GDSS is a suitable tool for good governance in water disciplines.

Acknowledgement

Mr. Ehsan Imani (University of Tabriz) has helped in the case study section and sincere appreciation is devoted to him. This paper will be presented in 2009 Amsterdam Conference on the Human Dimensions of Global Environmental Change, 2-4 December, Amsterdam (Netherlands), and herby the efforts of the conference organizers are so appreciated.

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