OPTIMAL WATER ALLOCATION BY EQUILIBRATING BETWEEN AGRICULTURAL AND ENVIRONMENTAL SECTORS IN RIVER BASINS

TAREBARI, H.[1] – JAVID, A. H.[1*] – MIRBAGHERI, S. A.[2] – FAHMI, H.[3]

[1]*Department of Environmental Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*
(phone: +98-914-353-6802)

[2]*Department of Civil and Environmental Engineering, K. N. Toosi University of Technology Tehran, Iran*

[3]*Ministry of Energy (MOE), Tehran, Iran*

**Corresponding author*
e-mail: a.javid@srbiau.ac.ir; phone: +98-214-486-2622; fax: +98-214-486-8539

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Abstract. The aim of this study was to optimal surface water resource management in the river-lake connected basins which are faced with water scarcity. In these regions, meeting the water demands of stakeholders along with supplying the environmental water requirements are critical and controversial issues. In this research, a multi-objective water allocation model which addresses the socio-economic and environmental objectives was developed, and a new simple method has been introduced for equilibrating between the sectors among which there are main conflicts. The proposed method was examined in the Zarrineh and Simineh rivers basins in Iran. These basins are the main surface water suppliers of the Lake Urmia which is facing a shrinkage challenge. As the agricultural sector is the main water user in the Lake Urmia basin, so there are significant conflicts between this sector and Lake Urmia's environment. Hence, the equilibrium status is obtained between these two stakeholders through drawing the graph of their utility functions versus risk parameter in the compromise programming technique. The proposed model can supply the domestic, industrial and agricultural demands 92.3, 100 and 60.8% respectively. Moreover, the ecological requirements of the rivers are supplied totally, and that of Lake Urmia amounts to 67.45%.
Keywords: *agricultural water, compromise programming, environmental demand, Lake Urmia, multi-objective optimization*

Introduction

Water scarcity is one of the crucial challenges in the arid and semi-arid areas. Many regions of Iran have encountered this problem. This issue is mainly due to an increment in water consumption, mismanagement of resources and the impact of climate change (Abbaspour et al., 2009; Madani, 2014; Shakib and Shojarastegari, 2017). One of Iran's major basins is the Lake Urmia basin in the northwest of Iran. In the recent years this region has been confronted with a significant decrease in water resources, such that, the volume of runoffs in this catchment area has reduced considerably during the past years, thereby, resulting in a decline in the surface area and level of the Lake Urmia (AghaKouchak et al., 2015; Alipour and Olya, 2015; Hassanzadeh et al., 2012). Under such conditions, the adoption of an optimal approach towards a sustainability of water resources is extremely essential. In accordance with the views of several experts, in relative to the sustainable management of water resources, three key factors in the minimum must be considered; and these are the socio-economic and environmental

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aspects (Braga, 2001; Poff et al., 2015; Zarghami and Szidarovszky, 2011). Hence, various studies have been performed based on multi-objective optimization models to consider different goals and reach sustainability (Oxley et al., 2016; Roozbahani et al., 2015; Xuan et al., 2012).

In order to address all the objectives simultaneously in the management process, the multi-objective optimization models have been widely applied and solved by the use of different methods like distance-base approaches (Zarghami and Szidarovszky, 2011). These methods attempt to minimize the distance of each solution from the ideal one or maximize from the worst (anti-ideal) response (Kao, 2010). In the present study, compromise programming (CP) technique as one of the mentioned methods is utilized to solve the proposed model.

In order to maintain sustainability in the ecosystem, efforts to balance the environmental flows with other competitive sectors are necessary (Acreman et al., 2014). Thereby, meeting the environmental requirements along with the water demands supplying is one of the most critical objectives for the optimal and sustainable allocation of water resources and also have been focused in the current study. In some of the studies, this aim has been supplemented as a constraint (Roozbahani et al., 2013; Yang and Yang, 2013) whereas, in others, it is in the form of an objective function (Mao et al., 2016). In this research, efforts have been made to supply simultaneously the environmental demand of the Lake Urmia and various water demands as well as considering relative priorities of water consumption sectors. With due attention to the fact that, climate change in most parts of the globe, has led to a decrease in water resources (IPCC, 2007; Stocker et al., 2013), accordingly in order to conserve the ecosystem of rivers and sustainability of water resources, assessing the impact of climate change and its implications in the management of water resources is imperative (Emam et al., 2015; Jiang et al., 2012; Lee et al., 2018; Omer et al., 2017). Hence, in this paper, the results of previous studies about climate change impacts on the runoff in the Simineh and Zarrineh rivers basins are considered (UNDP, 2016). In addition to climate change, human activities especially agricultural development also plays an important role in surface runoff volumes (Aghakhani et al., 2018; Barnett et al., 2008; Scanlon et al., 2007; Xu et al., 2013). Also one of the main characteristics of this research is determining the amount of agricultural consumption with respect to raise the environmental demand satisfying to the desirable level. As regards the amount of water available, it is limited in the semiarid areas, so competitions amongst the various stakeholders and appearance of disagreements are inevitable. Also, the various researchers have often utilized conflict resolution techniques based on the game theory, which include cooperative and non-cooperative game methods to resolve disagreements (Bazargan-Lari et al., 2009; Madani et al., 2014; Mianabadi et al., 2014; Salazar et al., 2007). But in this research, a new and simple way is introduced to reduce the competition and reach an agreement between the agricultural sector (as a major consumer of water) and Lake Urmia (as an environmental stakeholder), in which the final approach has been obtained by finding a suitable amount of risk parameter—as a term of CP equation—and selecting appropriate weight coefficients for objective functions. It should be noted that, determining of relative importance or weights for various objectives in the decision-making process of water resource management is an importance and an implicit issue (Can and Houck, 1984; Prakash et al., 2015), so the introduced method can be helpful in this regard.

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In the above-mentioned method, the optimal equilibrium point between the agricultural and environmental sectors is determined which indicates the largest equal satisfaction (utility) level for both sides. Furthermore, water demand increase because of the population growth and water resource development in the future is considered in this research. The formulation of the model and objective functions, as well as the equilibrating process, is entirely described hereunder.

Study area and data

The Zarrineh and Simineh rivers, which are located in the northwest of Iran are about 300 and 200 km in length respectively. These two rivers supply a crucial portion of the surface inflows to Lake Urmia, such that, for the past 60 years, more than half of the surface water resources of the lake were provided by these rivers. The average long-term surface water resources of the Zarrineh river basin are 2590 million m^3 and the surface water resources of the Simineh river basin are 655 million m^3. The Martyr Kazemi Dam, with the active volume of 654 million m^3, is the largest dam of the Lake Urmia Basin, which is situated on the Zarrineh River and is most vital in supplying the different sectors requirements in the sub-basin of this river. Similarly, the two dams, Sarough and Cheraghveis, which have also been constructed on the major tributaries of Zarrineh River, will soon be exploited (MGC, 2012). Moreover, due to the Lake's drying up over the past two decades, meeting its environmental water requirements is crucial and the main sources for such a supply are the two mentioned rivers. One of the imperative complexities in this basin is the reduction of runoff inputs to the Lake Urmia and water consumption increasing, particularly, in the agricultural sector (ULRP, 2015). Moreover studies demonstrate that climate change in the Zarrineh and Simineh rivers sub-basins has caused a reduction of the volume of water inflows, such that according to Iran's Third National Communication report to UNFCCC, 21% decrease in the average volume of runoffs in the case study area within the period of 2015-2045 in comparison with the long-term average under the pessimistic scenario, could be assumed due to climate change impacts (UNDP, 2016). With due attention to the high consumption (of water) in the agricultural sector of the Lake Urmia basin and its low efficiency, in order to supply the lake's demand, the water consumption volume in the agricultural sector, must be reduced by a considerable amount. In fact, the most critical competition is between the agricultural sector and the lake's environment. *Figure 1* illustrates the schematic of the sub-basins of Zarrineh River and Simineh River including the location of their reservoirs, water inflows and demand points.

In this research, the water resource allocation model has been developed, based on long-term average data and the schematic of the case study area has been shown in *Figure 1*. The amount of surface water resources in the catchment area is based on the National Water Master Plan Study of Lake Urmia Basin (MGC, 2012) and according to the report on the impacts of climate change in the studied sub-basins (UNDP, 2016). In fact, the inflows' water volume in the modeling process is assumed 79% (i.e. 21% decrease) of the long-term (60 years) average values. The water demand in the domestic, industrial, and agricultural sectors are also based on the estimated demand amount for the year 2041, as well as dams which will be under operation at that time are considered in the modeling process. Also, the ecological demands of rivers have been calculated by the modified Montana Method, approved by the Iranian Ministry of Energy (Torabi Palatkaleh et al., 2010).

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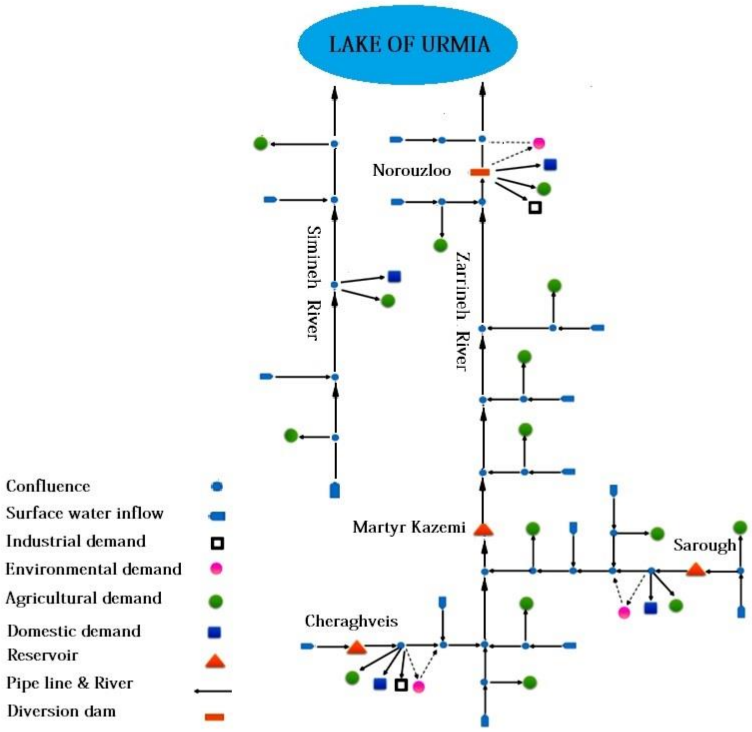

Figure1. *Schematic of the southern region of Lake Urmia basin (sub-basins of Zarrineh and Simineh rivers)*

Methods

In order to provide a sustainable approach in the management of surface water resources, various aspects of water resource management including the environmental and socio-economic aspects have been considered in the process of the proposed multi-objective optimization model. The model's goals have been implemented using the objective functions as well as the various constraints in the modeling. The water allocation modeling is principled on the status of the catchment area network, as presented in *Figure 1*, and also by using the various equations that will be introduced in the follows. The environmental water requirements of the rivers have been identified as a demand node in the downstream of each dam, in respect to its return flow proportion to the river, is equal to one. In continuation, the formulation of the model and the objective functions shall be explained.

Model formulation

Equations and constraints

The following equations and constraints are included in the proposed model: water balance constraint at node *a* (*Eq. 1*); upper and lower limits of allocated water volume for demand *k* at time *t* (*Eq. 2*); upper and lower limits of shortage parameter (*Eq. 3*); the formula of calculation the minimum acceptable volume of supplying demand *k* at time *t* (*Eq. 4*); water balance constraint at reservoir d (*Eq. 5*); upper and lower limits of reservoir *d* at time *t* (*Eq. 6*); the upper limit of reservoirs' outflow volume in a month (*Eq. 7*); the formula of calculation the return flow volume from demand k at time t to surface water (*Eq. 8*).

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$$SW_{a,t} + \sum_{t}\sum_{b\in UP_a} Q(b,a,t) = \sum_{t}\sum_{e\in DW_a} R(a,e,t) + \sum_{t}\sum_{k\in k_a} X(a,k,t) \quad \forall\, a,t \qquad \text{(Eq.1)}$$

$$X_{min}(k,t) \le X\,(k,t) + X_{sh}(k,t) \le dem\,(k,t) \qquad \forall\, k,t \qquad \text{(Eq.2)}$$

$$0 \le X_{sh}(k,t) \;\le X_{min}(k,t) \qquad \forall\, k,t \qquad \text{(Eq.3)}$$

$$X_{min}\,(k,t) = \alpha \times dem\,(k,t) \qquad \forall\, k,t \qquad \text{(Eq.4)}$$

$$S(d,t) = S(d,t-1) + Q(d,t) - R(d,t) - Ev(d,t) \qquad \forall\, d,t \qquad \text{(Eq.5)}$$

$$S_{min}(d) \le \; S(d,t) \;\le\; S_{max}(d) \qquad \forall\, d,t \qquad \text{(Eq.6)}$$

$$R(d,t) \;\le\; R_{max}(d\,) \qquad \forall\, d,t \qquad \text{(Eq.7)}$$

$$Q(k,a,t) = \; X(k,t) \;\times Ret(k,t) \qquad ;k \in UP_a \qquad \forall\, d,t \qquad \text{(Eq.8)}$$

where
a,b,e: the index of nodes
d: the index of reservoirs
dem(k,t): the water need of demand k in the month t
DW_a: the set of nodes in the downstream of *a*
Ev(d,t): the amount of water evaporation in the reservoir d in the month t
k: the index of water demand nodes
K_a: the set of demand nodes that get water from the node a
lk: the index of Lake Urmia
Q: the volume of water inflow to the reservoir d in the month t
Q(d,t): the volume of water inflow to the reservoir d in the month t
R(d,t): the volume of water discharged from the reservoir d in the month t
$R_{max}(d)$: the maximum output volume capacity from reservoir d in a period of one month
Ret (k,t): the return water ratio from the demand k to the allocated amount in month t (%)
S(d,0): the initial volume of water stored in reservoir d
S(d,t): the volume of water present in reservoir d in the month t
$S_{max}(d,t)$: the maximum storage capacity of reservoir d
$S_{min}(d)$: the initial volume of water stored in reservoir d
$Sw_{a,t}$: the volume of surface water produced at a distance of node a and its upstream nodes in the month t
t: the index of the time step
Up_a: the set of nodes in the upstream of a
X(a,k,t): the allocated water volume from node a to node b in the month t ($k \in K_a, t \in T$)
X(k,t): the water allocated for the requirements of node k in the month t
$X_{sh}(k,t)$: the difference between the minimum acceptable and allocated water to demand k in month t

In *Equation 4* the parameter α is determined based on experts' opinions and is equal to 80%, 60%, 50% and 40% for the domestic, industrial, environmental and agricultural

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sectors respectively. Likewise, the *Equation 9* has been proposed to estimate the environmental water requirements of Lake Urmia:

$$ED_{lk} = TED_{lk} \times \omega \quad \text{(Eq.9)}$$

where TED_{lk} is the total environmental demand for Lake Urmia per year (million m^3) which was caculated in the past study; ED_{lk} is the part of environmental demand of the lake which must be supplied by the sub-basins of the Zarrineh River and Simineh River (million m^3); ω is the share of Zarrineh and Simineh rivers in surface water reaching to the Lake Urmia (%). Indeed by means of above equation, the share of case study area in the supplying of surface wate resources for Lake Urmia will be calculated.

According to the past research, in the abovementioned equation TED_{lk} is equal to 3,086 million m^3 (Abbaspour and Nazaridoust, 2007), and based on the reported data by the Iranian Ministry of Energy, 52% (ω) of the inflow surface water to Lake Urmia is supplied by the Zarrineh and Simineh rivers in the long-term period. Hence, the ED_{lk} value is equivalent to 1605 million m^3.

Objective functions

Objective 1: The first objective function is developed to meet the needs of water consumption sectors as well as to satisfy the environmental demand of the rivers, in which each stakeholder has a certain relative priority. These priorities, which are characterized by applying relative weight coefficients to each section, are proposed according to the experts' opinions as the values offered in *Table 1*.

Table 1. *Relative weights of water demand sectors*

Sector	Agriculture	Industry	Rivers' Environment	Domestic
Relative weight (γ_i)	1	5	10	**50**

The first objective function is defined in terms of the total percentage supplied for the various sections according to their relative weight; and its equation is as follows (*Eq. 10*):

$$Z_1 = \sum_i \gamma_i \times sup_i \quad \text{(Eq.10)}$$

The more quantity of this function will be more favorable. In the abovementioned relation γ_i is the weight of section *i* and sup_i is the annual percentage of supplied demand for section *i* throughout the entire case study area and is computed according to *Equation 11*:

$$sup_i = \frac{\sum_{ki}\sum_t x(ki,t)}{\sum_{ki}\sum_t dem(ki,t)} \quad \text{(Eq.11)}$$

where ki is the index of demand nodes of section i; X (ki,t) is the amount of allocated water to ki in the month t.

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Objective 2: The second objective function is to consider the economic aspect of water resources management in the catchment area and represents the total net cost of water allocation to the different sectors. It is expressed as follows (*Eq. 12*):

$$Z_2 = \sum_t \sum_k \left(\left(C_{k,t} - G_{k,t} \right) \times X_{k,t} \right) \quad \text{(Eq.12)}$$

where $C_{k,t}$ is the cost of allocating a unit of water for the demand of k in the month t; $G_{k,t}$ is revenues from the sale of water for the demand k in the month t (water tariff); $X_{k,t}$ is volume of water allocated for the demand of k in the month t. Therefore, the smaller, the abovementioned objective is in amount, it is more appropriate and the results will be closer to the optimal response.

Objective 3: As illustrated in *Equation 3,* in order to avoid the infeasibility of the optimization model in severe drought conditions, where meeting the minimum requirements for the entire sectors is not possible, the water shortage parameter is defined, which, in the lack of the presence of sufficient resources in order to satisfy the minimum acceptable supply level of each demand node, at a time or in several series of time, this parameter shall get a positive amount. It is obvious that, in the optimum mode, all the values of this parameter must be nil or as small as possible. Hence, the function of Z_3 which illustrates the sum of these parameters values, is developed as a one the objectives of the model, so by minimizing its value the better results will be achieved (*Eq. 13*).

$$Z_3 = \sum_t \sum_k (X_{sh}(k,t)) \quad \text{(Eq.13)}$$

According to above explanations and objective functions formulation, the optimal results of the developed model will be achieved by maximizing the Z_1 as well as minimizing the Z_2 and Z_3 values. In order to convert the three-objective model to a single-objective one, the CP method was applied which is introduced below.

Compromise programming

Compromise Programming (CP) is one of the most commonly used methods for converting multi-objective into a single-objective problem, which has been successful in the past studies of water resource planning (Fattahi and Fayyaz, 2010; Roozbahani et al., 2015; Shiau and Lee, 2005). Thereby, in the present research by using this method, the multi-objective model becomes a single-objective model and then the prospects of assigning different weights for objective functions and a change in the risk parameter (p) are accomplished and solved by the GAMS software and using CONOPT solver (Brooke et al., 1998). This method is based on decreasing the distance between the final solution and the ideal response. Its advantages are possibility to weigh the varied objectives and taking into consideration the risk taking as well as the risk aversion approaches. The general form of CP equation is expressed as follows (*Eq. 14*):

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$$D_p(x) = \left[\sum_{y=1}^{n_y} w_y^p \cdot \bar{\beta}_y^p\right]^{1/p} \quad \text{(Eq.14)}$$

In the abovementioned equation, $\bar{\beta}_y$ represents the normalized value of the objective function y. w_y denotes the weight of each function and p is a positive parameter which designates the decision-maker's risk involvement. The smaller p value shows that the decision-maker have placed greater importance on small deviations from ideal point which indicates adopting risk aversion approach; whereas, the larger this parameter is, expresses a vaster and higher risk taking by the decision-maker, such that greater deviations shall have more importance in determining the Dp(x) value. In order to normalize the value of the objective functions of a given set of responses, the following relation is utilized (*Eq. 15*):

$$\bar{\beta}_y = \left(\frac{Z_y^* - Z_y(x)}{Z_y^* - Z_y^{\ddot{}}}\right) \quad \text{(Eq.15)}$$

where Z_y^* *and*the worst possible values, for the objective function are the best and $Z_y^{\ddot{}}$ Z_y. For example, if the aim is to maximize Z_y, its most possible largest value, shall be the best amount and its smallest possible value shall also be the worst response.

As mentioned above, in the given equation, the parameter w_y denotes the relative weight of the objective function *y* and the parameter p demonstrates the degree of risks involved in the management of resources. So as to determine the optimal response, the various values of p ($p \in P$), together with the different weight sets, were put to test in *Equation 14*.

$$P = \{1, 2, 3, 4, \dots, 99, 100\}$$

In order to produce varied sets of weights, 3 members are selected from a set of K - which includes 18 different numbers in the range of 0.05 to 0.9- on the condition that, their summation is equivalent to 1. It should be noted that, the smallest weight value is assumed equal to 0.05. Since the sum of the weights of the three objective functions is equal to 1, thereby, the largest possible value for the weight of each function will be equivalent to 0.9.

$$K = \{0.05, 0.1, 0.15, \dots, 0.85, 0.9\}$$

Principled on the above descriptions, the 171 various sets of weights are produced. After the implementation of the model, with the each series of weights and different values of p, the results obtained, and initially assessed. This determined that, the results of using all of the weights series for domestic, industrial and rivers' environmental sectors were acceptable for at least one of the values of p, in which the minimum acceptable of water supplying in these sectors were satisfied.

Though, in the agricultural sector, in the case that, the weight of the cost function (second objective function) is equivalent to or greater than 0.2, for the all values of p, the supplying level was less than 40%, which is lower than the minimal acceptable

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supply level. Therefore, with due attention to the fact that the second objective function must get one of the following values, such as 0.05 and 0.1 or 0.15, only 51 varied series of weights will be acceptable and surveyed in continuation. In *Table 2,* the weighted coefficient of the objective function are shown in each of n-series of weight including series of weight 1(SW1) to series of weight 51(SW51).

Table 2. *Values of weights of the objective functions in varied weight series*

SWN	Values of relative weights			SWN	Values of relative weights		
	Z1 (SUPPLY)	**Z2 (COST)**	**Z3 (SHORTAGE)**		**Z1 (SUPPLY)**	**Z2 (COST)**	**Z3 (SHORTAGE)**
SW1	0.05	0.05	0.9	SW27	0.45	0.1	0.45
SW2	0.1	0.05	0.85	SW28	0.5	0.1	0.4
SW3	0.15	0.05	0.8	SW29	0.55	0.1	0.35
SW4	0.2	0.05	0.75	SW30	0.6	0.1	0.3
SW5	0.25	0.05	0.7	SW31	0.65	0.1	0.25
SW6	0.3	0.05	0.65	SW32	0.7	0.1	0.2
SW7	0.35	0.05	0.6	SW33	0.75	0.1	0.15
SW8	0.4	0.05	0.55	SW34	0.8	0.1	0.1
SW9	0.45	0.05	0.5	SW35	0.85	0.1	0.05
SW10	0.5	0.05	0.45	SW36	0.05	0.15	0.8
SW11	0.55	0.05	0.4	SW37	0.1	0.15	0.75
SW12	0.6	0.05	0.35	SW38	0.15	0.15	0.7
SW13	0.65	0.05	0.3	SW39	0.2	0.15	0.65
SW14	0.7	0.05	0.25	SW40	0.25	0.15	0.6
SW15	0.75	0.05	0.2	SW41	0.3	0.15	0.55
SW16	0.8	0.05	0.15	SW42	0.35	0.15	0.5
SW17	0.85	0.05	0.1	SW43	0.4	0.15	0.45
SW18	0.9	0.05	0.05	SW44	0.45	0.15	0.4
SW19	0.05	0.1	0.85	SW45	0.5	0.15	0.35
SW20	0.1	0.1	0.8	SW46	0.55	0.15	0.3
SW21	0.15	0.1	0.75	SW47	0.6	0.15	0.25
SW22	0.2	0.1	0.7	SW48	0.65	0.15	0.2
SW23	0.25	0.1	0.65	SW49	0.7	0.15	0.15
SW24	0.3	0.1	0.6	SW50	0.75	0.15	0.1
SW25	0.35	0.1	0.55	SW51	0.8	0.15	0.05
SW26	0.4	0.1	0.5				

The CP model is solved for all of the series of weights and varied values of p from 1 to 100. Now, with due attention to the fact that, satisfying the environmental water requirements for Lake Urmia is one of the most important issues under consideration, so the final result should be able to satisfy the requirements of the various sectors and also that of the lake to the most possible level. Given that, the amount for domestic and industrial demand is very much lower than that of the agricultural sector, and meeting of domestic and industrial requirements has always been of high priority from the viewpoint of decision-makers (*Table 1*), in all cases (i.e. in the all series of weights and the different amounts of the p), these sectors have been satisfied at a desirable level.

Similarly, due to the high volume of consumption in the agricultural sector there is competitiveness and a major dispute between this sector and Lake Urmia. Hence, by rendering a new method, efforts have been made to signify the equilibrium point between these two sectors, which is identified as the optimal response of the model.

In order to establish a balance between the agricultural sector and the Lake Urmia, the utility function in both the sections have been defined (*Eq. 16*) then, by plotting the graphs of the utility and p against each other for the both of them, in the same coordinate system, the intersection points of the two mentioned graphs identified, which in fact, is the point of equilibrium between the agricultural and lake environmental demand. Some of the weights series have a just one intersection point, whilst some others have several intersection points. In the case that, the graphs have more than one intersection point, the point which displays the highest utility is introduced as the point of equilibrium. The utility function equation for the agricultural sector and Lake Urmia has been proposed as follows:

$$f_i\,(x_i\,) = \begin{cases} 0 & , \quad x < x_{i,min} \\ \dfrac{x_i - x_{i,min}}{Dem_i - x_{i,min}} & , \quad x \geq x_{i,min} \end{cases} \tag{Eq.16}$$

In the abovementioned relation, x_i is the annual amount allotted to, and Dem_i and is the annual demand of sector *i*. Moreover, $x_{i,min}$ also is the minimum acceptable amount for each sector that must be allotted annually. In *Figure 2*, the utility changes of the agricultural sector and Lake Urmia are illustrated in relative to the impacts of changes of p in the CP method using SW1 ($\{0.05, 0.05, 0.9\}$).

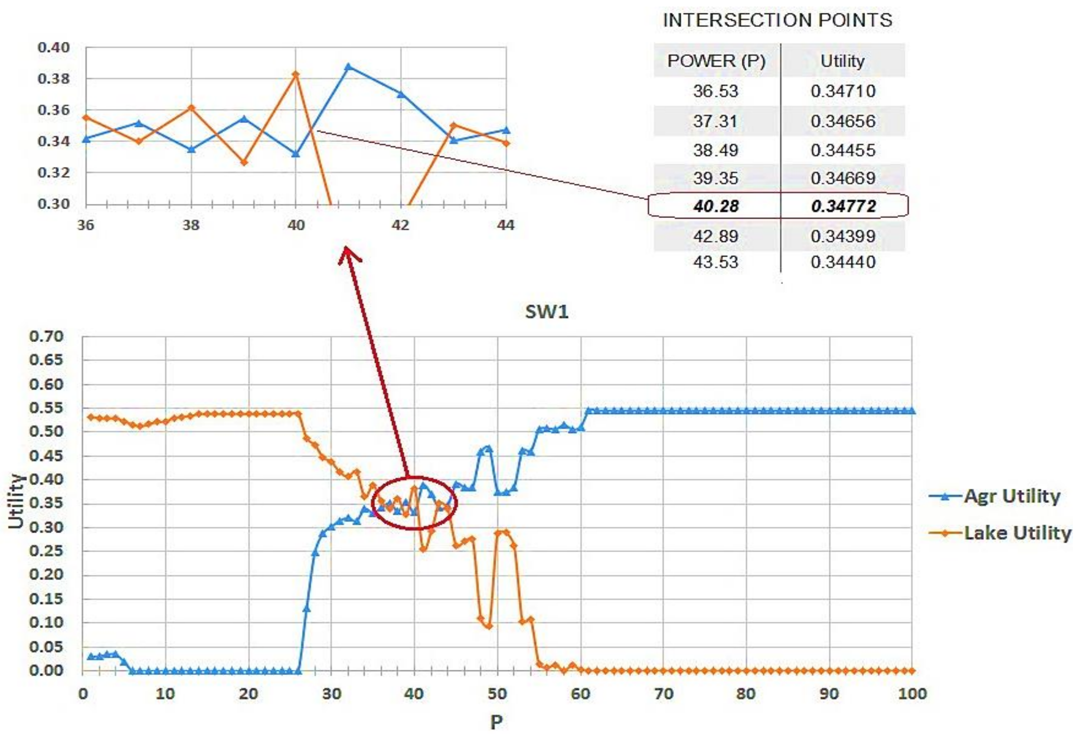

Figure 2. *Variation of utility in the agricultural sector and environmental water requirements of the lake for different p by use of SW1*

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Likewise, the characteristics of the utility intersections of these two sections are shown alongside the graph. According to this diagram, there are 7 equilibrium points for this series of weights. From amongst these points the most desirable condition shall be selected. In this case (SW1) the *p* and utility values in the optimal point of equilibrium, equates to 40.28 and 0.3477 respectively. For the entire 51 series weight, the above method was performed and each of the equilibrium points specified.

In addition to SW1 conditions which are shown in *Figure 2*, the utility changes using SW5, SW10, SW20, SW30, SW40 and SW50 for various *p* are demonstrated in *Figure 3*.

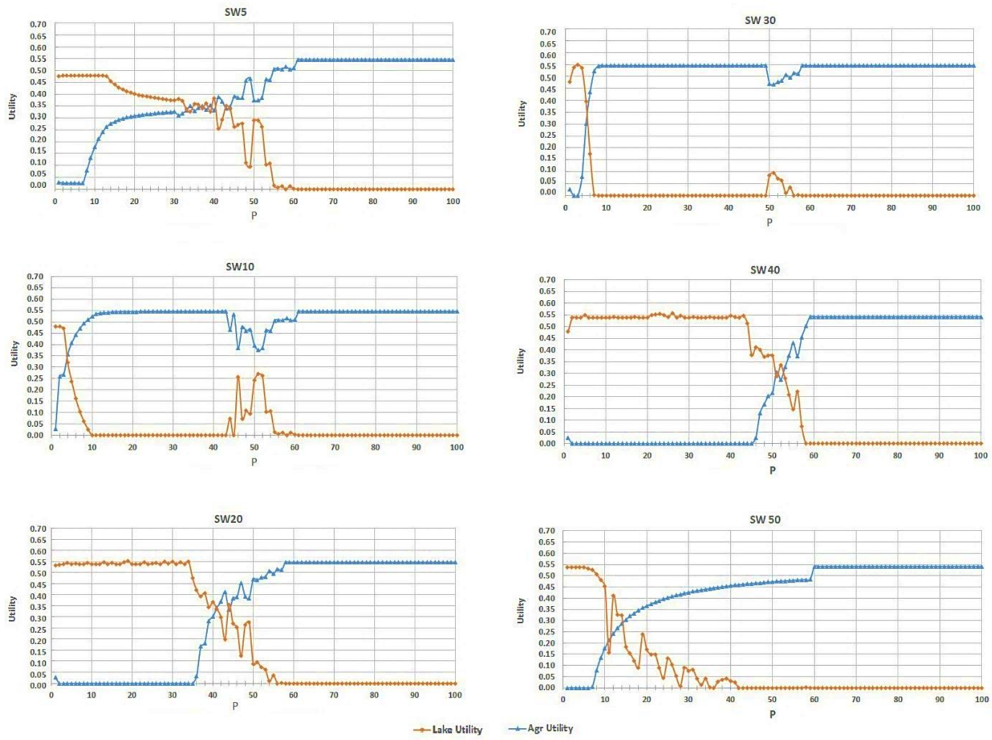

Figure 3. *Variations of utility in the agricultural sector and Lake Urmia for different P and series weight: SW5, SW50, SW40, SW30, SW20 and SW10*

Results and discussion

In *Table 2*, for each set of weights, the amount of p and the corresponding utility value are specified at the equilibrium point. In accordance with the results rendered, the utility value varies from 0.23 to 0.3477 for various situations. The equilibrium point which creates the highest amount of utility in both of the sectors shall be selected as the final approach. As can be observed in *Table 3*, the set of weights of 1 to 5 have of the same equilibrium points that indicates the highest utility value. Thereby, the results of CP model with the P=40.28 and with abovementioned sets of weights for objective functions (SW1 to SW5) are introduced as the optimal resource allocation approach which indicate Utility of 0.3477 for agricultural and lake's environment. According to various sets of weights given for the objective functions in *Table 2*, in the sets of 1 to 5, the economic function's weight in all the five conditions is equivalent to 0.05, the shortage function's weight varies from 0.7 to 0.9 and the supply function's alters from

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0.05 to 0.25. The results indicated that, the weight of the economic function plays a crucial role in the results of the CP model and its change will have a greater impact on the result, rather than the change in the weight of supply function or shortage function. Similarly, in all the sets of weights, an increment in the value of p from 60 to 100, the utility of the agricultural sector gains its maximum amount and the utility of the lake gets to its minimum. By decreasing in the p value (adopting the risk aversion approach) this process has been reversed in the various sets of weight, such that, the utility of the agricultural sector will be lower than the utility of the lake's environment. Hence, on the basis of the results, by increasing the level of risk taking, the higher level of agricultural demand supplying will be achieved.

Table 3. *The values of the risk parameter and the utility at the equilibrium points in the different sets of weight*

SWN	Intersection point		SWN	Intersection point	
	P	Utility		P	Utility
SW1	40.28	0.3477	SW27	42.36	0.2796
SW2	40.28	0.3477	SW28	15.79	0.3163
SW3	40.28	0.3477	SW29	7.80	0.3353
SW4	40.28	0.3477	SW30	5.26	0.3366
SW5	40.28	0.3477	SW31	4.06	0.3429
SW6	43.53	0.3444	SW32	3.35	0.3136
SW7	43.53	0.3444	SW33	2.80	0.3039
SW8	5.90	0.3440	SW34	2.51	0.2339
SW9	4.66	0.3440	SW35	2.45	0.2493
SW10	3.84	0.3440	SW36	52.55	0.3031
SW11	3.35	0.3437	SW37	52.55	0.3031
SW12	2.75	0.3439	SW38	52.55	0.3031
SW13	2.49	0.3421	SW39	52.55	0.3031
SW14	2.28	0.3386	SW40	52.55	0.3031
SW15	1.95	0.3370	SW41	52.55	0.3031
SW16	1.57	0.2763	SW42	52.44	0.2976
SW17	1.44	0.2516	SW43	52.39	0.2916
SW18	1.27	0.3355	SW44	53.00	0.2848
SW19	44.16	0.3418	SW45	53.47	0.2753
SW20	44.16	0.3418	SW46	54.27	0.2749
SW21	44.16	0.3418	SW47	54.97	0.2777
SW22	44.16	0.3418	SW48	54.96	0.2741
SW23	44.16	0.3418	SW49	41.08	0.2748
SW24	44.16	0.3418	SW50	14.23	0.2904
SW25	44.16	0.3418	SW51	8.39	0.2821
SW26	44.16	0.3418			

The results relative to the allocation of the various sectors in the proposed conditions have been rendered in *Table 4*. According to these results, the amount allotted to the domestic sector is 92.3% and that of the industrial sector is 100%. Similarly, the minimum environmental demand of the rivers has been estimated as 100%. The reason for the high level of supply of the industrial sector in comparison with the domestic sector, despite its smaller relative priority, is the lower demand of that sector (29 million m^3) than domestic one (331 million m^3). It should be mentioned that in the proposed approach, the amount of the annual flow of rivers has been more than their environmental demand. This may be due to cost minimizing and attempts to increase inflow water into the Lake Urmia during equilibration process between agriculture and the environment. Moreover as it shown in the *Table 4,* satisfying level of the agricultural sector is about 61%, which may be cause of economic concerns. Hence, in order to avoid unfavorable economic consequences, the water savings policies must be considered. For example adopting suitable cultivation patterns and using more efficient irrigation systems could be helpful methods.

Table 4. *The percentage of supply of the various sectors and volume of water allocated to each section in the case study area*

	Domestic	**Industry**	**Agriculture**	**Lake Urmia**
Demand volume (million m^3)	331	29	2300	1605
Supply level (%)	92.3%	100%	60.8%	67.45%
Allocated volume (mcm)	305.5	29	1398	1082

Likewise, in accordance with *Figure 4,* in the specified weight of the cost function, if the weight of the shortage function (the third objective function) is greater than the supply function (the first objective function), the utility value will be around its optimal value (i.e. utility value in the equilibrium point). By increasing the weight of the economic function from 0.05 to 0.1 and also from 0.1 to 0.15, the maximum value of the utility in the equilibrating point between the two sections becomes smaller. This is such that, by choosing 0.05, 0.1 and 0.15 as the weight of cost function, the amount of utility attained at the optimal equilibrium point equates to 0.3477, 0.3429 and 0.3030 respectively.

The present paper’s output is a situation in which the main parties of a conflict reach to equilibrium. In this status the optimal value of risk parameter in the CP method could be found, in which the main parties of the dispute agree on a specific utility level. In other words, when the risk parameter is not equal to optimal value (i.e. risk parameter in the equilibrium point), the utility level of one part will be greater than the other one, so arising conflicts are possible. The results show that by changing in the level of decision makers’ risk appetite, the stakeholders can reach an agreement and also reduce their conflicts. Moreover, through applying the CP technique the various objectives or concepts of sustainable water resource management including economic, environmental and social preferences are taken into account simultaneously. Consequently the introduced methodology could support the sustainability of water resource system.

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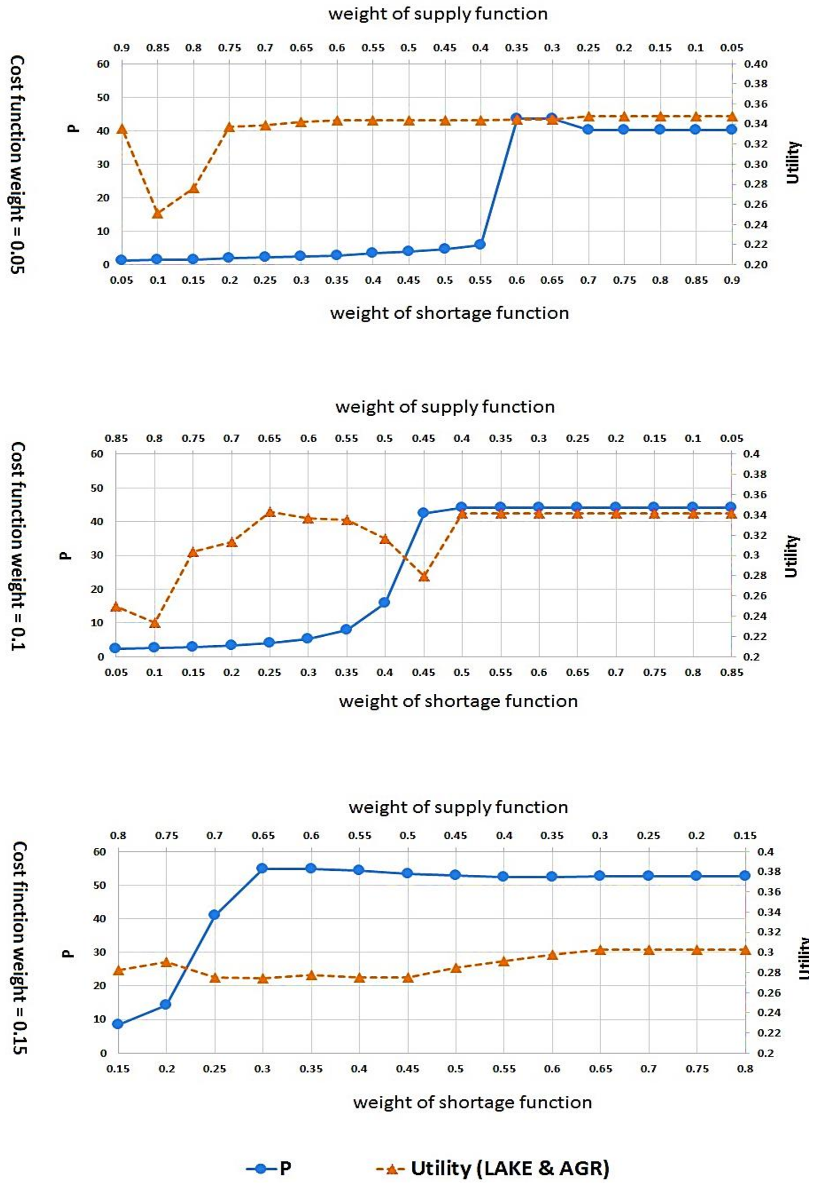

Figure 4. *the value of risk parameters and utility in the equilibrium points for various weights of the objective functions*

Conclusion

In this research, a multi-objective optimization model for the allocation of surface water resources is presented in the river-lake connected basins. This model addresses the socio-economic and environmental aspects of water resource management as the key factors of the sustainability, and also considers the ecological requirements of rivers and the environmental water demand of the lake. The model is implemented in the Zarrineh and Simineh rivers sub-basins in the southern part of the Lake Urmia basin in Iran. The proposed model was solved using the CP technique and several responses were generated by assuming 171 different sets of weights for the objective functions and assigning 100 different values for the risk parameter (p). Overviewing the results of the CP model showed that 120 of 171 produced sets of weights must be eliminated due to unacceptable deficit value in the agricultural sector. Hence, 51 various sets of weights

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were analyzed in detail to reach an optimal approach. To reduce competition between the Lake's environmental demand and agricultural sector -as the main rival of the Lake Urmia- the equilibrium points between these two competitors are found for each set of weighs through drawing the graph of utility vs p. These points illustrate the equal utility level for both sectors. This issue helps to reduce conflicts between them, because by increasing the utility degree on one side in comparison to its value in the equilibrium point, the other side's utility will be decrease, and it can be the cause of dissatisfaction. The equilibrium point that indicates the largest utility level for the agricultural and the lake is selected as the best point. The results of model in the condition of the best equilibrium point, support the water resources sustainability, and simultaneously provide desirable level of utility for all stakeholders.

Furthermore, in formulation of the presented model the priority of the sectors to each other, as well as the minimum acceptable supply level of stakeholders are taken into account. Moreover, the water demand growth in future and reduction of available water resource due to climate change impacts under pessimistic scenario are considered. According to the results, the supply level of domestic is 92.3% and the industrial one is 100% which are favorable values. The results show that adoption of risk taking approach is in line with satisfying the demand of the sectors with lower priority like agricultural sector in this research.

The proposed method can be used to manage water resources in the river-lake systems and reduce the interaction between the environmental supporters and cultivators or between the other sectors are in conflicts, through the agreement of the parties on the equilibrium point.

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