Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/04/jls.htm
2015 Vol. 5 (S4), pp. 682-691/Hiva
Research Article

OPTIMIZATION OF WATER WITHDRAWAL FOR IRRIGATION PURPOSE USING GOAL PROGRAMMING

***Ahmadi Hiva**
Department of Industrial Engineering, Amir Kabir University Tehran, Iran
**Author for Correspondence*

ABSTRACT
In this paper, we aim to optimize water withdrawal for irrigation purpose using goal production programming. In doing so, we develop a multi-criteria decision making model which produces satisfactory results under uncertainty. We explore the satisfaction of people concerned as well as environmental consequences of water resources operation. Further, we study the impact of parameter changes on model output by analyzing the sensitivity. We employed the stochastic goal programming model to manage water resources of Firooz Abad plain in 2014. The results indicated that this model is able to achieve multiple goals and enables decision maker to investigate various scenarios of parameter values by defining risk parameters.

Keywords: *Water Resources Management, Stochastic Goal Programming, Uncertainty*

INTRODUCTION
The policies adopted by governments and their impacts on water resources have been a widespread topic for research on water resources management. Researchers have proposed various methods for efficient allocation and management of water resources (e.g. Bashir *et al.,* 2009; Chang *et al.,* 1996; Hipel, 1992; Chang *et al.,* 1996; Maqsood *et al.,* 2005; Jairaj and Vedula, 2000; Zarghami and Szidarovszky, 2009; Bravo and Gonzalez, 2009; Cai and Ringler, 2007; Raju and Kumar, 2005; Riesgo and Gomez-Limon, 2006; Madani, 2013; Mehdiyoun, 2014; Zhou *et al.,* 2013; Wang *et al.,* 2013; Wang and Huang, 2013; Wang and Huang, 2012; Mehdiyoun, 2014).
Guo *et al.,* (2010) proposed a random fuzzy two-stage programming model for managing water resources under uncertainty. This approach was able to model the changes in government policies and their impacts on water resources. This model was also able to determine the best method for managing scarce water resources by analyzing various scenarios. Li *et al.,* (2010) proposed a two-stage model for managing water withdrawal from river basin. This model was able to analyze the impact of predefined government policies on water resources based on stochastic programming and to help decision makers to determine the right amount of withdrawal under uncertainty.
Li *et al.,* (2010) proposed a mathematical fuzzy programming method for investigating water resources management policies. Burte *et al.,* (2009) proposed a simulation model for analyzing various policies of withdrawing agricultural and drinking water and their impacts on the amount of available water in future. They also studied social and economic consequences of each policy. Burte *et al.,* (2009) referred to a number of potential policies which have to be evaluated and classified in a multi-criteria decision making context. These policies include executive long-term measures and programs before, during and after drought. Rossi *et al.,* (2005) conducted a case study in India and determined an irrigation system with optimal performance using multi-criteria techniques.
In the field of agriculture, Gomez-Limon and Martinez (2006) determined an optimal quantity of the crops in a river basin in Spain and proposed a model for optimizing the welfare of local farmers. Bravo and Gonzalez (2009) proposed a decision-making model under uncertainty in order to control surface and underground water resources. Decision making under uncertainty is one of the popular research topics in the field of management, engineering and economics (Clemen, 1996). Operation research scholars have proposed scientific approaches so that decision makers can make best decisions under uncertainty. One of the programming techniques under uncertainty is chance-constrained programming which enables to solve simple problems under certain conditions (Charnes and Cooper, 1959). However, solving big problems by this technique would be very complicated and costly. Random fuzzy expected value method (Liu and Liu,

2003) is another approach for solving stochastic goal programming problems. Stochastic goal programming is a multi-criteria model which supports decision making and produces successful results for a series of weighted target equations under uncertainty. This type of modeling has a root in the theory of maximizing expected goodness under risk conditions (Markowitz, 1952). Stochastic goal programming is an absolute risk-based approach under uncertainty (Ballestero, 2001). This approach is less complicated and more easy to use than random fuzzy expected value method (Sahoo and Biswal, 2005).

While the amount of withdrawal from water resources with a focus on environmental aspects is one of the key topics in the field of water resources programming, no study has been conducted for water resources planners to determine the authorized amount of withdrawal from surface waters and to control the withdrawal from underground water under uncertainty, considering economic and ecological aspects of water resources in the framework of a supportive model. Stochastic goal programming model is a multi-criteria decision making model under uncertainty.

Belaid and Torre (2010) and Chizari *et al.,* (2005) employed goal programming model to determine economic value of water. They used preference goal programming for optimal water allocation in Mahabad dam, one of the ten wateriest dams in Iran. The results indicated that the water allocated to agriculture and drinking may be increased according to the goals of decision makers and the order of precedence of goals. Nadereh and Sabouhi (2011) used stochastic goal programming model to analyze the water flow entering the reservoirs of Mahabad dam. According to the results, using this model enables reservoir manager to make optimal planning for various conditions such as wet periods and drought.

Aouni *et al.,* (2005) employed stochastic goal programming method to merge decision maker's preferences and determine goodness function under uncertainty. Al-Zahrani and Ahmad (2004) used stochastic goal programming technique to plan water resources consumption, assuming that demand and supply are uncertain. In another study, Bravo and Gonzalez (2009) employed stochastic goal programming method to determine the allocation of surface and underground water to farmers under uncertainty based on economic and environmental goals.

While this approach has been used in many domestic studies, few studies have been made on goal programming under uncertainty. Stochastic constraint programming is the first technique to include uncertainty (Sabouhi *et al.,* 2006). Stochastic constraint programming has been proposed by Charnes and Cooper (1959). The uncertainty of resources has been studied with the assumption that decision maker wishes to make a probable situation in relation to the frequency of existing resources. However, this method suits simple problems and cannot be used in complicated problems. Goal programming technique under uncertainty based on absolute risk aversion is called stochastic goal programming. This technique produces its results through the relationship between expected goodness theory and linear weighted goal programming model under uncertainty (Ballestero, 2001).

In this study, we employ stochastic goal programming. This technique weights the changeability of goals based on matrixes of changeability of decision makers' preference and risk factors relating to the goals.

MATERIALS AND METHODS

Research Method

Fars province is suffering a water crisis, especially in agricultural sector. At present, 75% of agricultural water of the province is supplied by underground water reservoirs. This figure is 55% for the whole country. Annual water withdrawal in Fars province has been estimated to be 700 million cubic meters. According to official reports, 67 out of 90 plains in Fars province have a negative underground water balance (Fars Province Planning Management Organization, 2015).

This reveals that many plains in the province, such as Firooz Abad plain, suffer a water crisis. At present, water withdrawal from underground water reservoirs of Firooz Abad plain is estimated to be 300 million cubic meters, which is two times the permitted withdrawal (South Development Study and Informatics Center, 2014).

If the drought persists, the agriculture in Firooz Abad plain will be unsustainable due to the imbalance between water supply and demand.

Table 1: Water resources values during 1993-2014

Year	Surface Water Value	Standard Underground Water Value	Complementary Underground Water Value
1993	33.84	107.087	180.533
1994	140.6	199.361	73.743
1995	72.595	149.0277	141.784
1996	42.1103	130.202	172.269
1997	63.6692	164.828	150.710
1998	68.1018	161.013	146.278
1999	72.595	193.3440	141.784
2000	214.379	263.8305	0
2001	55.4083	75.1156	158.97
2002	102.958	200.7815	111.421
2003	176.702	274.477	37.6777
2004	54.4009	112.117	159.979
2005	116.459	235.4693	97.9207
2006	92.28	139.5533	122.099
2007	40.9014	85.29977	173.478
2008	20.752	93.4470	193.627
2009	29.8197	157.0207	184.560
2010	22.7677	129.7087	191.612
2011	83.0117	185.4745	131.368
2012	184.157	262.0097	30.2228
2013	37.6776	124.2154	176.702
2014	26.998	137.022	187.381

In this model, two groups of random variables are used. The first group consists of random variables of Max_1, Max_2 and Max_3.The second group consists of random variables of EP_1, EP_2 and EP_3. This group of random variables is obtained from the multiplication of environmental consequences factor by Max variable. In other words, EP variable indicates the environmental consequence connected with each value of annual water. It should be noted that $Environment_2$=$Environment_3$, because they both relate to underground water resources. According to experts of Boushehr Province Agriculture Jihad Organization, from each unit of underground water used for agriculture, 0.2 unit is wasted. This figure has been estimated to be 0.6 unit for surface water. So, $Environment_1$= 0.6 and $Environment_2$= 0.2. Table 1 contains EP_1, EP_2 and EP_3 variables for each year.

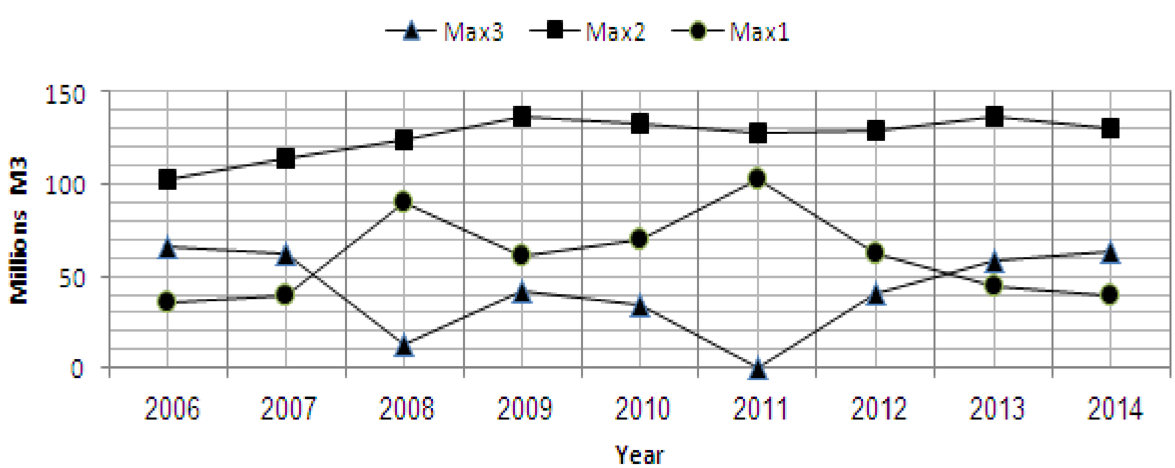

Figure 1: Maximum of withdrawal

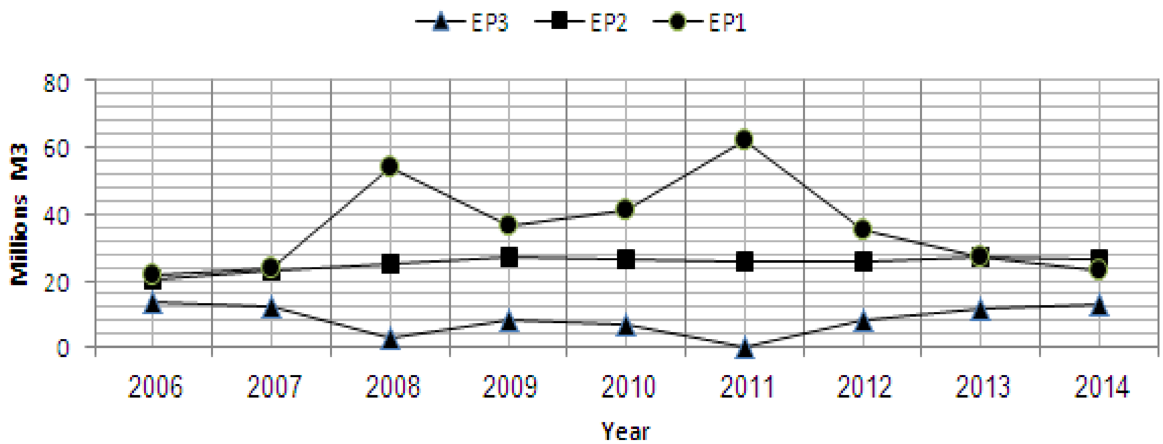

Figure 2: Maximum of environmental consequences

In this model, three decision variables (REC_I, i = 1, 2, 3) have been defined. Each of these three variables is in 0-1 range. As mentioned earlier, REC_i variable can reduce Max_i values if necessary. For instance, if REC_1 = 0.7, it means that only 70% of available surface waters should be used for irrigation in order to reach optimal conditions (sustainable water).

The first goal is to manage the fields. To define this goal, we asked the experts of Boushehr Province Agriculture Jihad Organization to determine an appropriate level for this goal based on the estimation of irrigation needs in Firooz Abad Plain. Annual irrigation needs of Firroz Abad Plain were determined to be 35.07 million cubic meters. According to this goal, the quality of agricultural sector should be improved. The quality is obtained when the entire need for irrigation the fields is met. Based on the review of past researches, there was no record of determining risk factor in agriculture sector, neither in the province nor in other points of the country. For this reason, the risk factor of agriculture sector was assumed to be 0.3 after consultation with the experts.

The second goal is to minimize environmental consequences of irrigation. This goal focuses on those on whom environmental consequences of water withdrawal for irrigation purpose are imposed. Therefore, we defined a goodness function under uncertainty for such people. This goodness function is dependent on the risk they take. This goal attempts to maximize the expected goodness, so that the goodness obtained from the targeted EP value ($EP_{0=}0.14$) is met. In this problem, EP_0 was an acceptable part of maximum bearable environmental consequences and was calculated as EP=22.74. In this equation, according to experts' views, the maximum of environmental consequences was multiplied by 0.14 in order to obtain EP_0.

Based on the above facts, we wrote stochastic goal programming model. As you can see in target function of the model, MAT matrix has to be computed first. MAT matrix is obtained from combination of MAT 1 and MAT 2 matrixes. MAT 1 covariance matrix is made by MAX and relates to the first goal. MAT 2 matrix is made by Environment and relates to the second goal.

Computing MAT matrix requires COM1 and COM2 combination factors, each consisting of two elements. $PREF_1$ and $PREF_2$ are the factors of decision maker's preferences for the first and second goals respectively. Based on the experts' views, we considered these two values to be equal. This means that both goals are equally important in stochastic goal programming model.

$RISK_1$ and $RISK_2$ parameters are the risk factors of Firooz Abad Plain farmers and all people who suffer irrigation-caused environmental consequences. In solving stochastic goal programming model, we first set $RISK_1$ coefficient on 0.35 like what Bravo M. and Gonzalez I. (2009) had proposed. Then we analyzed risk factor sensitivity.

We supposed the risk factor of population points ($RISK_{POP}$) to be the same as that of other Iranians. Risk factor of population points of Iran was estimated to be 0.41. Therefore, we set $RISK_{POP}$ on 0.41. Having MAT matrix, target function 3 was rewritten as MAT_{min}.

Table 2: Symbols used in the model

Symbol	Description
Max_1	Maximum surface water flow in each year, which is dependent on annual rainfall.
Max_2	Maximum underground water flow in each year, which is dependent on annual rainfall.
Max_3	Maximum complementary underground water flow, which is dependent on drought or wet period in each year. To compute Max_3 for each year, Max_1 should be reduced from maximum of Max_1.
$Environment_1$	Environmental consequence for each Max_1 unit
$Environment_2$	Environmental consequence for each Max_2 unit
$Environment_3$	Environmental consequence for each Max_3 unit
$EP = Environment_i \times Max_i$	Environmental consequence relating to each annual water value
REC_1	Reducer of Max_1 value
REC_2	Reducer of Max_2 value
REC_3	Reducer of Max_3 value
$Max= REC_1*Max_1+ REC_2*Max_2+ REC_3*Max_3$.	Total needed water for irrigation
$EP= REC_1*EP_1+ REC_2*EP_2+ REC_3*EP_3$	Minimization of environmental consequences
MAT_1	Maximum water goal
MAT_2	Minimum environmental consequences goal
COM	Combination factors
PREF	Preference factors
RISK	Risk factors
$RISK_{POP}$	Population risk factors
$MAT=RISK_1*MAT_1+RISK_{pop}*MAT_2$	First and second goals
$MAT_{min}= [REC_1\ REC_2\ REC_3] * MAT *[REC_1\ REC_2\ REC_3]$	Third goal

RESULTS AND DISCUSSION

Results

Actual Results

Having stochastic goal programing model of the problem, we solved it using Lingo 11 software package. The values of REC_1, REC_2 and REC_3 were 0.14, 0.12 and 0.22 respectively. These values indicated that only 0.14 of maximum surface water and 0.12 of maximum underground water obtained from rainfall must be consumed in agriculture sector and 0.22 of maximum complementary underground water must be allocated to agricultural sector in order to achieve an optimal situation (sustainable water). For the constraint relating to the first goal, deficiency value was 0. This variable for the constraint of the second goal was 59.11. In other words, optimal solution of the model indicates that the management goal in agricultural sector, which is linked to farmers' preferences, has been fulfilled. However, environmental consequence of this solution is more than the specified amount.

Table 2 contains the results obtained from sensitivity analysis for the first goal. This table shows the value of each decision variable for increase or decrease by 5 million units in the amount of water needed for irrigating Firooz Abad fields. To better understand the results obtained from sensitivity analysis, we investigate one of the scenarios. If value of the first goal drops by 5 units, REC_1 value will decrease by 15%. In the same time, REC_2 and REC_3 will decrease by 12% and 18% respectively.

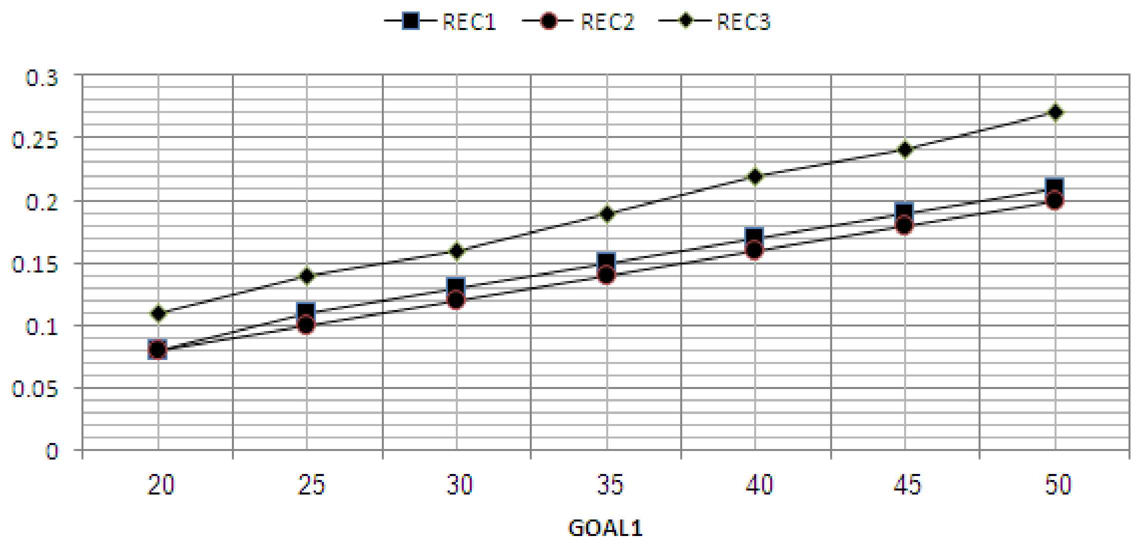

Figure 3: Sensitivity analysis for the first goal

But if target value increases to 10 cubic meters, REC_1, REC_2 and REC_3 will increase by 13%, 14% and 15% respectively. As you can see in the figure, the increase in the first goal value results in a continuous increase of REC_1, REC_2 and REC_3 (13%, 14% and 15% respectively).
To analyze the sensitivity of risk factor in agricultural sector, we assumed the risk factor of local farmers to be 0.35. Now, we investigate the impact of change in this factor on the model.

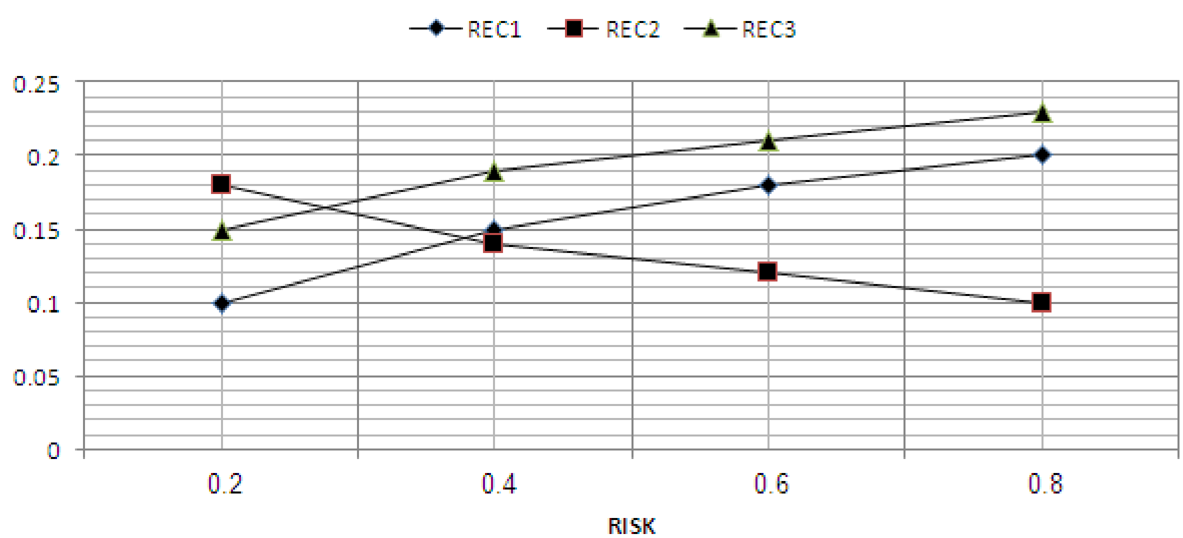

Figure 4: Sensitivity analysis of the model for the change in $RISK_1$

As you can see in the figure, when agricultural sector risk factor ($RISK_1$) increases, REC_1 and REC_2 will increase but REC_3 will decrease. This means that the more farmers take risk, the more surface and complementary underground water is consumed and the less water is withdrawn from underground water reservoirs. To analyze the sensitivity of $Environment_1$, we set environmental consequences coefficient relating to this resource on 0.2 given that underground water reservoirs in Firooz Abad plain are used by modern irrigation methods. But since surface water resources are used by traditional methods, the factor of effectiveness of environmental consequences is 0.6 for each unit of this resource. This factor may be reduced to 0.2 if modern irrigation methods such as drop irrigation and pressurized irrigation are used.

Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/04/jls.htm
2015 Vol. 5 (S4), pp. 682-691/Hiva
Research Article

With this change, the first goal is fulfilled. In addition, REC_1 and REC_3 decrease to 0.13 and 0.06 respectively, while REC_2 increases. Generally, these changes lead to the reduction of water withdrawal from the said resources, albeit cost-profit analysis must be made for these changes.

Simulation Results

We used the recorded data of the province for a period of one year in order to determine a distribution with the best fitness for all hours. We tested fitness quality using Kolmogorov-Smirnov goodness of fit test, which indicated that lognormal distribution had a good fitness in confidence level of 5%. We extracted the cumulative distribution functions of the pool input using the software. Figure 5 illustrates the inversed cumulative distribution function for confidences of 0.25, 0.5 and 0.75, which represent low input, normal input and filled input.

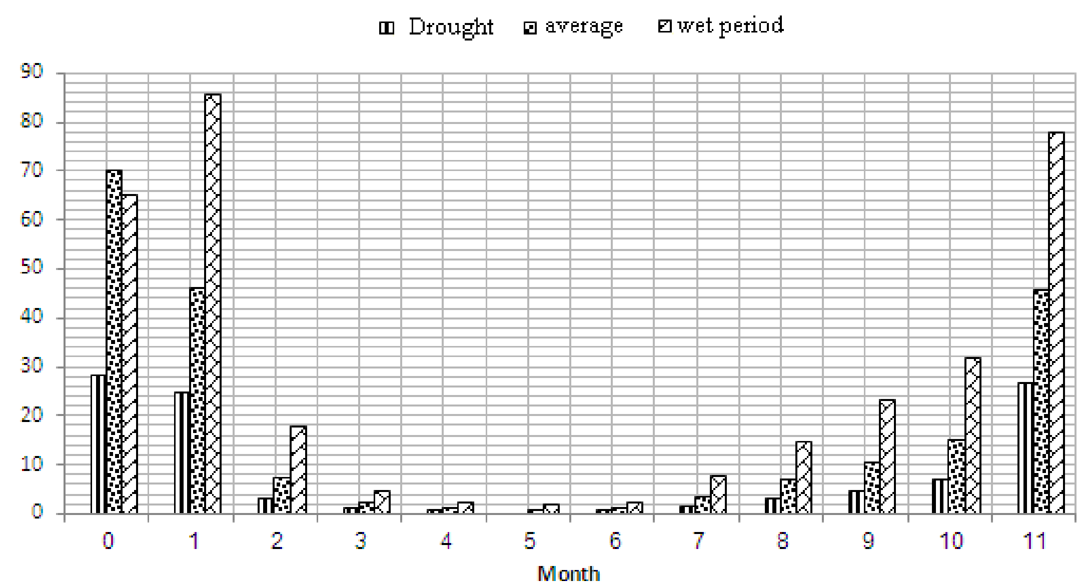

Figure 5: The average input of the pool for three rainfall levels

We used the extracted model for three water supply modes which may represent a 12-month period (25%, 50% and -75%). In each mode, we investigated the impact of low input on system goals and operation policies in three water application levels (25%, 50% and 100%) and produced the scenario of input scheme.

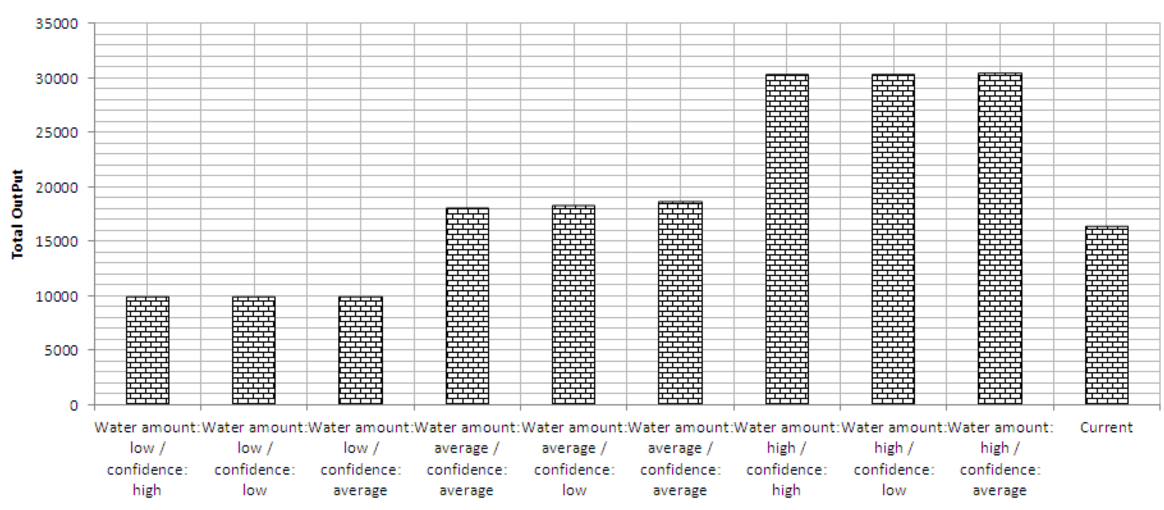

Figure 6: Final output in different scenarios for risk and input flow

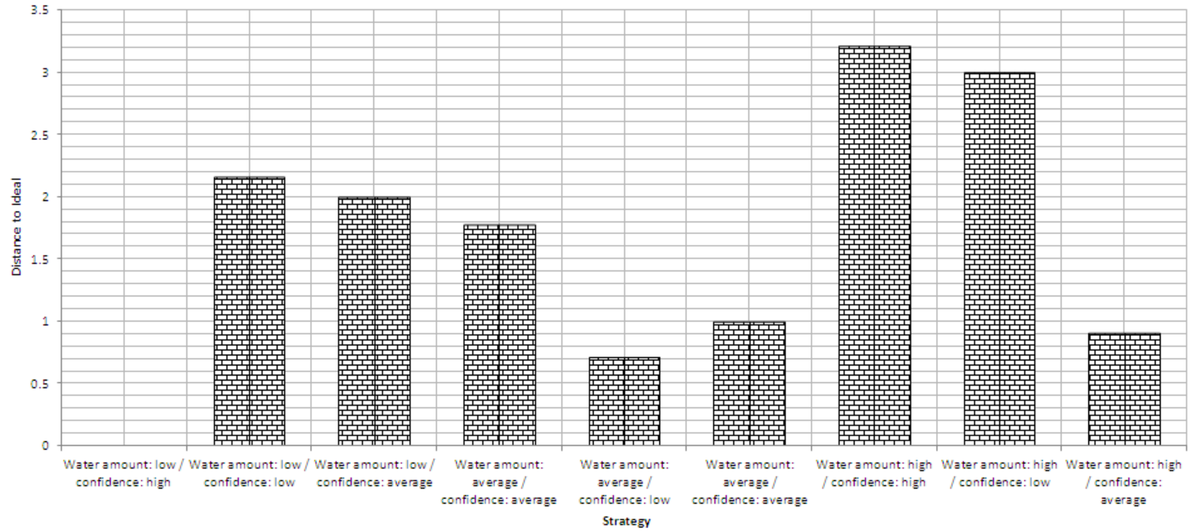

Figure 7: Distance to ideal in different scenarios for risk and input flow

The results contained in the above figures indicate that the application of low input in different conditions may improve withdrawal planning. In normal conditions and full input, application of 25% of input produces the best strategies (25-50 and 25-75). In drought, the adjustment of confidence parameter produces the best strategy (25-50). The strategy of 25-50 is the best strategy in normal months.

Conclusion

Stochastic goal programming is an efficient method in water resources management which is able to coordinate conflicting goals such as full irrigation of all fields and the avoidance of environmental consequences of irrigation. Moreover, by analyzing the sensitivity of parameters of stochastic goal programming model, one can obviously see the impact of changes in irrigation technology on the achievement of goals and the reduction of water resources consumption. In addition, sensitivity analysis indicates that withdrawal from underground water resources may be reduced by adopting efficient solutions and improving risk-taking level of local farmers.

REFERENCES

AL-Zahrani MA and Ahmad AM (2004). Stochastic Goal Programming model for optimal blending of desalinated water with groundwater water. *Resources Management* **18** 339–352.

Aouni B, Ben Abdelaziz F and Martel JM (2005). Decision-maker's preferences modeling in the stochastic goal programming. *European Journal of Operational Research* **162** 610-618.

Ballestero E (2001). Stochastic goal programming: A mean-variance approach. *European Journal of Operational Research* **131** 476-481.

Bashir M, Tanakamaru H and Tada A (2009). Spatial and temporal analysis of evapotranspiration using satellite remote sensing data: a case study in the Gezira Scheme. *Sudanian Journal of Environmental Information* **13**(2) 86-92.

Belaid A and Torre DL (2010). A generalized stochastic goal programming model. *Applied Mathematics and Computation* **215**(12) 4347-4357.

Bravo M and Gonzalez I (2009). Applying stochastic goal programming: a case study on water use planning. *European Journal of Operational Research* **196**(3) 1123-1129.

Bravo M and Gonzalez I (2009). Applying stochastic goal programming: A case study on water use planning. *European Journal of Operational Research* **196** 1123-1129.

Burte J, Jamin J, Coudrain A, Frischkorn H and Martins E (2009). Simulations of multipurpose water availability in a semi-arid catchment under different management strategies. *Agricultural Water Management* **96** 1181-1190.

Cai X and Ringler C (2007). Balancing agricultural and environmental water needs in China: Alternative scenarios and policy options. *Water Policy* **9** 95–108.
Chang N, Wen C, Chen Y and Yong Y (1996). A grey fuzzy multiobjective programming approach for the optimal planning of a reservoir watershed, part A: theoretical development. *Water Resources* **30** 2329-2340.
Chang N, Wen C, Chen Y and Yong Y (1996). A grey fuzzy multiobjective programming approach for the optimal planning of a reservoir watershed. Part B: application. *Water Resources* **30** 2341-2352.
Charnes A and Cooper WW (1959). Chance-constrained programming. *Management Science* **6** 73-79.
Chizari A, Sharzeie Q and Keramatzadeh A (2005). Determination of economic value of water with an approach to goal programming: case study: Barzoshirvan Dam. *Economic Research Journal* 66-71: 39.
Gomez-Limon J and Martinez Y (2006). Multi-criteria modelling of irrigation water market at basin level: A Spanish case study. *European Journal of Operational Research* **173**(1) 313-336.
Guo P, Huang G, Zhu H and Wang X (2010). A two-stage programming approach for water resources management under randomness and fuzziness. *Environmental Modelling & Software* **25** 1573-1581.
Hipel K (1992). Multiple objective decision making in water resource. *Water Resources Bulletin* **28**(1) 3-13.
Jairaj P and Vedula S (2000)./ Multireservoir system optimization using fuzzy mathematical programming. *Water Resource Management* **14** 457-472.
Li W, Li Y, Li C and Huang G (2010). An inexact two-stage water management model for planning agricultural irrigation under uncertainty. *Agricultural Water Management* **97** 1905-1914.
Li Y, Huang G and Nie S (2010). Planning water resources management systems using a fuzzy-boundary intervalstochastic programming method. *Advances in Water Resources* **33** 1105-1117.
Liu B and Liu Y (2003). Expected value operator of random fuzzy variable and random fuzzy expected value models. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* **11** 195-215.
Madani K (2013). Modeling International Climate Change Negotiations More Responsibly: Can Highly Simplified Game Theory Models Provide Reliable Policy Insights? *Ecological Economics* **90** 68e76, Available: http://dx.doi.org/10.1016/ j.ecolecon.2013.02.011.
Madani K and Dinar A (2013). Exogenous regulatory institutions for sustainable management of common pool resources: application to groundwater. *Water Resources and Economics* **2-3** 57e76.
Madani K, Sheikhmohammady M, Mokhtari S, Moradi M and Xanthopoulos P (2013). Social planner's solution for the Caspian Sea conflict. *Group Decision and Negotiation* **23**(3) 579, Available: http://dx.doi.org/10.1007/s10726-013-9345-7 (in press).
Maqsood I, Huang G and Yeomans J (2005). An interval-parameter fuzzy two-stage stochastic program for water resources management under uncertainty. *European Journal of Operations Research* **167** 208-225.
Markowitz H (1952). Portfolio Selection. *Journal of Finance* (7) 77-91.
Mehdiyoun K (2014). Ownership of oil and gas resources in the Caspian sea. *American Journal of International Law* **94** 179e189.
Nader H and Sabouhi Sabouni M (2011). Mahabad dam water allocation management using preference goal programming. *Agriculture Economy Research* **3**(3) 1-16.
Raju K and Kumar D (2005). Fuzzy multicriteria decision making in irrigation planning. *Irrigation and Drainage* **54**(4) 455-465.
Read L *et al.*, (2014). Optimality versus stability in water resource allocation. *Journal of Environmental Management* **133** 343-354.
Riesgo L and Gomez-Limon LA (2006). Multi-criteria policy scenario analysis for public regulation of irrigated agriculture. *Agricultural Systems* **91** 1-28.
Rossi G, Cancelliere A and Giuliano G (2005). Case study: Multicriteria assessment of drought mitigation measures. *Journal of Water Resources Planning and Management-ASCE* **131**(6) 449-457.

Sabouhi Sabouni M, Soltani Q, Zibaei M and Torkamani J (2006). Determination of efficient low irrigation solution with a view to maximizing social benefits. *Agriculture and Development Economy* 56.
Sahoo N and Biswal M (2005). Computation of some stochastic linear programming problems with Cauchy and extreme value distributions. *International Journal of Computer Mathematics* **82**(6) 685-698.
Wang S and Huang GH (2012). Identifying optimal water resources allocation strategies through an interactive multi-stage stochastic fuzzy programming approach. *Water Resources Management* **26** 2015–2038 .
Wang S and Huang GH (2013). A coupled factorial-analysis-based interval programming approach and its application to air quality management. *Journal of the Air & Waste Management Association* **63** 179–189.
Wang S, Huang GH and Veawab A (2013). A sequential factorial analysis approach to characterize the effects of uncertainties for supporting air quality management. *Atmospheric Environment* **67** 304–312.
Zarghami M and Szidarovszky F (2009). Stochastic-fuzzy multi criteria decision making for robustwater resourcesmanagement. *Stochastic Environmental Resource Risk Assessment* **23** 329-339.
Zhou Y, Huang GH and Yang B (2013). Water resources management under multiparameter interactions: A factorial multi-stage stochastic programming approach. *Omega* **41** 559–573.