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Water Resources Sustainable Allocation: Case Study; AlborzProvince, Iran

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ABSTRACT

Shortage of water resources, particularly in the developing countries, is a global problem and this is due to the rapid growth of population and water pollution resulting from uncontrolled economic development. In some regions, it is difficult to allocate water to all the consumers in a desirable manner and thus logical allocation of water resources is considered a significant issue. This article presents a multi-objective model for efficient allocation of water resources from the perspective of sustainable development. The model used in this study is the one used for allocation of water resources in Alborz province where water shortage will be unavoidable due to rapid growth in demands for water. The results gained from this study indicate that with the increase for water demand, the efficient allocation can be carried out in a way that different users of water resources will suffer the least and thus move towards sustainability.

Key words: water, multi-objective programming, sustainable development.

Introduction

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' [5]. Most researchers seek to create a system for quantifying and determining the obligations related to sustainability in the existing agricultural systems. For an active, random and purposeful system, sustainability is defined as the capability for continuing with the future. Nowadays, the important issue in sustainability is how it can be used as operational criteria in management of agricultural systems [1].

In recent decades, attention to sustainability and management of water resources as vital sources of life has become the main and significant issue. This evolution is the result of awareness and belief of the national and international circles with regard to the realities of time. The fact is such natural resources as water, air, energy, soil, and biological species are in fact limited and rebirth and revival of these resources is much more costly and time-consuming than their protection [2]. For instance and based on the opinions of different researchers, 10 to 50 per cent of water consumption in the agricultural sector, 40 to 80 percent of water consumption in the industry and about 30 per cent of urban water consumption can be decreased without even hurting the main aim [4].

In most regions, it is difficult to allocate water as it is desired by the consumers and thus logical allocation of water resources is considered a significant issue. To this aim, this article aims to present a model for efficient allocation of water resources from the viewpoint of sustainable development in Alborz province. In order to accomplish this aim, two criteria are to be presented for making it efficient to allocate water resources, i.e. satisfying the demands for existing water resources as well as maintaining the integrity of ecosystems. These two criteria can be defined as follows [3]:

a. Satisfying the demand for existing water resources: sustainable development first needs to satisfy the needs for current developments, thus the satisfaction of current demands for water resources is the first criteria of efficient allocation of water resources. Satisfaction of demands for water includes providing water for all current consumers such as the ones in the agriculture, industry, and drinkable water provision sectors. All these users can be categorized as the economic users because water is vital for maintaining the production and it has direct benefits for these consumers of water. These benefits can be calculated on the basis of the amount of provided water.
b. Maintaining the integrity of ecosystems: maintaining the integrity of the eco-system in for the sake of supporting natural resources for

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satisfying the needs of future generations. Recently and particularly in the developing countries, development tends to damage the environment and this is in fact in contradiction with sustainability. In order to have efficient water allocation, maintaining the integrity of the eco-system means providing enough water for improving the eco-system and the environment. This is a particular use of water and it is related to public consumption. There is no direct benefit in such water provision and is cannot be calculated based on the money that is spent. However, water supply needs to be secured for the eco-systems; otherwise they will be ruined and the cycle of natural resources cannot be maintained, thus will affect the needs of future generations [6].

Methodology:

The data required for this research has been collected from Water Resources Management Organization at Alborz and Tehran Provinces as well as Jihad-Agriculture Organization of Alborz province. In order to achieve the aim of this study, a multi-objective programming model has been used. The functions of the purpose of the model can be gained using the criteria of efficient allocation of water. In order to choose an objective function, two principles needs to be observed:

1. objective function needs to be computable; in other words, it needs to have a definite value so to calculate it using the target functions,
2. The number of target functions must be kept to the minimum as much as possible in a way to simplify the method of solving the model.

On the basis of these two principles, two objective functions were selected. One was maximizing the economic benefits and the other was maximizing water supply for the users of the eco-system.

Economic benefits maximizing: Economic benefits include supplying water for all the economic users (such as agriculture, industry, public sector and other users). This function can be written as follows:

$$MAX \sum_{j=1}^{m} c_j x_j \tag{1}$$

Where *m* is the number of users of water in the region, is the amount of provided water for user j, is the benefits of one unit of water supply for user j; if is fixed, then the function is a linear function.

Maximizing water supply of the eco-system: this function is maximizing the supply of water for the eco-system and thus it can be written as:

$$\text{MAX Q} \tag{2}$$

Q is the water supply for the user of the eco-system; if there is more than one user for the eco-system; then q is the sum of the total water supply for the users of the eco-system in the region.

Constraints:

The following constraints have been considered in the model:

(a) water resources constraints

$$\sum_{j=1}^{m} x_j + q \le R \tag{3}$$

R is the total available water resources in the whole region.

B- Water quantity constraints

$$x_j \le xm_j \tag{4}$$

J=1, 2, m

Where, xm_j is the maximum amount of demand for water for user *j*.

C. fairness constraints

$$x_j \ge w_j xm_j \tag{5}$$

j=1, 2, m

Where w_j, is percentage that the water demands to be secured for user j. This constraint guarantees that the users with low profitability could access the minimum amount of water in order to maintain their main activities and avoid the situation in which all water resources are allocated to the users with high profitability.

Model of Allocating Water Resources:

Combining purpose and constraint functions, the model of allocation of water resources can be written as follows:

$$\begin{cases} MAX \sum_{j=1}^{m} c_j x_j \\ MAXq \\ s.t. \\ \sum_{j=1}^{m} x_j \le R \\ x_j \le xm_j \\ x_j \ge w_j xm_j \\ j = 1,2,\ldots\ldots,m \end{cases} \tag{6}$$

Solution of the Model:

This model is an optimal multi-objective model with two objective functions. The method of solving

Adv. Environ. Biol., 6(2): 912-915, 2012

this model has been presented here. Our main goal here is changing the second objective function of the multi-objective model to one single-objective model. Therefore, multi-objective model can be changed to a single-objective model. Solving this single-objective model can provide consistent solutions. On this basis, the coefficient for selecting an efficient solution of a multi-objective model will be provided.

Changing the Model:

Changing the second objective function to a constraint is done as follows:

$$q = qs_i \tag{7}$$

In which is the water resources allocated to the user of the ecosystem and it includes n values between qs_{max} and qs_{min}; is the maximum amount of demand for water of the eco-system, while is the minimum amount of demand for water and it can be calculated as follows:

$$qs_{\min} = w \bullet qs_{\max} \tag{8}$$

Where w is a coefficient. After this operation, the multi-objective model will be turned into a single-objective model as follows:

$$\begin{cases} MAX \sum_{j=1}^{m} c_j x_j \\ s.t. \\ \sum_{j=1}^{m} x_j + q \le R \\ x_j \le xm_j \\ q = qs_i \\ x_j \ge w_j xm_j \\ j = 1,2,....., m \end{cases} \tag{9}$$

qshas n values. Therefore, we have n models with single here, which are linear efficient-finding models and in order to find the efficient solution of this model, the linear programming can be used.

Optimal solution:

The optimal solution of the multi-objective model is gained through the solutions of the undesirable solutions and this can be considered a transactional and mutual method. The decision-maker compares all the undesirable solutions with each other and with regard to one or more than one prior index, such as maximum provision of water of for the ecosystem or gaining more direct benefit and satisfying the demand for daily water, selects the optimal solutions.

Results:

Case Study:

Alborz province, located at the West of Tehran province in Iran, is the case study of the present research. Due to being located near the capital city of Iran, this province attracts many immigrants and it enjoys particular political, economic, cultural, and commercial situation. Based on the forecasts, this province, as many other provinces in Iran will face water shortage in the coming years and if the present trend of consumption continues. It is indeed not possible to answer all water needs. In this part of the study, we will use the above mentioned model for allocation of water resources in Alborz province.

Water Resources and the current Demands for Water:

Based on the predictions, the water resources in Alborz province will be 14151 (10000 cubic meter) in 2016, while the total demand for water will be 16829 (10000 cubic meter). The consumers of water in this province can be categorized into urban consumers (URB), industrial water (IND), agricultural water (IRR), rural water (RUR), and ecosystem consumption (ECO). The amount of water that is predicted to be used by these users is stated in Table 1.

Table1: Predicted demand for water (10000 m3).

Year	Total	URB	IND	IRR	RUR	ECO
2016	16829	5974	1235	6729	1991	900

Source: Water Resources Management Organization, 2011, and research findings

The figures stated in the table1 indicate that if no amount of water is transferred from the surrounding areas to this place, the guarantee rate of water supply in 2016 will be just 84.08 and thus water shortage will be dramatic. In such situation, the logical allocation of water resources to each user will be the key issue for the region’s sustainable development.

Multi-objective allocation model for water:

Multi-objective allocation model for water is based on equation 6 and the values of cj and w_j coefficients have been stated in Table 2.

Table 2: Coefficients of the multi-objective model of water allocation (unit=1000 Rials).

	URB	IND	IRR	RUR	ECO
C	5.4	628.70	63.680	1.62	
W	0.9	0	0.8	0.9	0.75

Source: research findings

The value of c for both urban and rural water is based on the rates in 2011. Meanwhile the value of this coefficient for industrial and rural water has gained from the amount of units of water consumption for industrial and agricultural productions.

Discussion:

Based on the method presented in this study, single-objective models are to be investigated. Here qs have 10 values as 10 scenarios and using the linear programming, model 9 is gained for 10 single-objective models. After solving these 10 models, water allocation projects are mentioned in Table 3. The results gained from this table demonstrate that water supply for rural, agricultural and urban water will stay the same, while water supply for the industries will increase with the decrease in water supply for the ecosystem.

Project 4 is chosen as the efficient answer in this study. This is due to the fact that guarantee rate of water supply for ecosystem reaches 81.05%, while reduction of water supply to other users will result in more reduction in the total direct benefits and the guarantee rate of water supply for the industry is still about 67%.

Table 3: Projects for allocation of water for single-purpose models.

Project	Ecosystem	Urban water	Industrial water	Agricultural water	Rural water
1	680	5376	919	5383	1791
2	710	5376	889	5383	1791
3	740	5376	859	5383	1791
4	770	5376	829	5383	1791
5	800	5376	799	5383	1791
6	830	5376	769	5383	1791
7	860	5376	739	5383	1791
8	890	5376	709	5383	1791
9	920	5376	679	5383	1791
10	950	5376	649	5383	1791

Source: research findings

Table 4: Results of allocation of water resources.

User	Total	URB	IND	ARR	RUR	ECO
Demand	16829	5974	1235	6729	1991	900
Allocation	14151	5376	829	5383	1791	770
Guarantee rate	84.08%	90%	67.12%	80%	90%	81%

Source: research findings

Results of water allocation in Table 4 indicate that the total guarantee rate of water supply is 84.08, while these rates for the ecosystems are 81%, urban water 90%, industrial water 67.12%, agricultural water 80%, and rural water 90%.

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