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OPTIMUM WATER RESOURCES ALLOCATION BY ARTIFICIAL IMMUNE SYSTEMS

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ABSTRACT

This study proposes an optimization model using Artificial Immune Systems (AIS) for allocation of water resources among different sectors, such as agriculture, industry, livestock production, drinking and domestic, environmental water demands; also for energy, tourism, mining, aquaculture and commercial water demands. The modified Clonal Selection Algorithm (modified Clonalg), which is a class of AIS, was used in the study. An objective function of the model was based on both maximum benefit (income) and optimum water satisfaction of the sectors. The model was implemented in a scenario covering the mentioned sectors for testing its performance efficacy. The results demonstrated that the model is applicable for the optimal water resources allocation.

Keywords: Water resources, water allocation, optimization, modelling, modified Clonalg.

1. INTRODUCTION

As is known, approximately %97 of the Earth's water consists of the oceans and seas. Rest of water resources are glaciers, groundwater and surface water, etc (Shiklomanov, 1993). Therefore, fresh water resources for drinking, domestic and utility water are so limited; consequently, allocation of limited water resources becomes a crucial optimization problem for the sectors.

In this regard, there are many studies concerning an optimum allocation of water resources; Shangguan et al. (2002), for instance, proposed the model of recurrence control for a regional optimum allocation of irrigation water resources, determining an overall maximum efficiency, Wang et al. (2003) proposed the cooperative game theoretic approach for solving the water allocation problems, Perera et al. (2005) presented REALM (resource allocation model) for management and planning of water supply, Sethi et al. (2006) improved the models of chance-constrained linear programming and deterministic linear programming for allocating available water resources and lands optimally on seasonal basis, Messner et al. (2006) applied an integrated methodological approach for a water allocation conflict in the German Spree River watershed, Letcher et al. (2007) provided the generalised conceptual framework for an integrated assessment modelling of water resources allocation, Li et al. (2009) improved the model of multistage fuzzy-stochastic programming for supporting sustainable water resources management and allocation, Nikoo et al. (2014) proposed the nonlinear interval optimization model based on simulating annealing and particle swarm optimization for optimal allocation of waste load and water in the downstream river, Das et al. (2015) improved the model of linear programming for optimal water resources and land allocation in different sectors of the Hirakud Canal Command, Roozbahani et al. (2015) introduced the model of multi–objective for optimal water allocation considering social, environmental, and economic benefits, Nguyen et al. (2016) proposed the improved ant colony optimization algorithm for optimum crop and irrigation water allocation, Li et al. (2017) developed the model of inexact fuzzy stochastic simulation-optimization programming for the optimum irrigation water allocation of the water sources, Zhang et al. (2017) improved the model of fuzzy credibility–constrained interval two-stage stochastic programming for optimizing a water distribution of the different industries based on a water demand estimation under multiple uncertainty conditions, Li et al. (2018) developed the model of interval linear multi–objective programming using a fuzzy programming method for the irrigation water allocation.

As an alternative to the related literature, a heuristic optimization model using the modified Clonalg was developed to allocate water resources for different sectors considering maximum satisfaction of water demand and maximum economic benefit in this study. The results showed that the model is useful and feasible in allocation and planning of water resources.

2. MATERIAL AND METHOD

2.1 Model Formulation

The modified Clonalg by Eryiğit (2015) was utilized to allocate water resources. The modified Clonalg was illustrated for optimization problems in Figure 1, where Ab is a population of antibody randomly created, *f* is the antibody's antigenic affinity (objective function), C is a population of cloned antibodies, C* is a population of the mutated antibodies. New genes are created for each antibody clone by considering the certain probability subject to an optimization problem, named as "probability rate" (PR) in the modified Clonalg. A clone number of the antibodies can be computed as the following (De Castro and Von Zuben, 2002):

$$N_C = \sum_{i=1}^{N_{Ab}} round(\beta \cdot N_{Ab}) \qquad i = 1, \cdots, N_{Ab} \tag{1}$$

where N_c is a total clone number, β is a coefficient of multiplying, "round" is a rounding operator for the integer.

A mutation rate can be calculated as below (De Castro and Von Zuben, 2002):

$$\alpha_i = \exp(-\rho \cdot f_i) \tag{2}$$

where α_i is a mutation rate, ρ is a coefficient of decay, and f_i is a value of antigenic affinity (a value of objective function) normalized between 0 and 1.

Description of Ab:

$$\begin{bmatrix} Ab_1 & = & x_{11} & \cdots & x_{1j} & \cdots & x_{1nd} \\ \vdots & & \vdots & & & & \vdots \\ Ab_i & = & x_{i1} & & \ddots & & x_{ind} \\ \vdots & & \vdots & & & & \vdots \\ Ab_{N_{Ab}} & = & x_{N_{Ab}1} & \cdots & x_{N_{Ab}j} & \cdots & x_{N_{Ab}nd} \end{bmatrix} \rightarrow \begin{bmatrix} f_1 \\ \vdots \\ f_i \\ \vdots \\ f_{N_{Ab}} \end{bmatrix} \qquad i=1,\cdots,N_{Ab} \qquad j=1,\cdots nd \tag{3}$$

where N_{Ab} is the total antibody number (population Ab), x_{ij} is a gene of Ab_i (decision variable of f_i), *nd* is a gene number of Ab_i. In this study, x_{ij} corresponds to an amount of water allocated to each sector. *f* was maximized depending on amounts of water (genes) constituted and mutated throughout processes of the modified Clonalg.

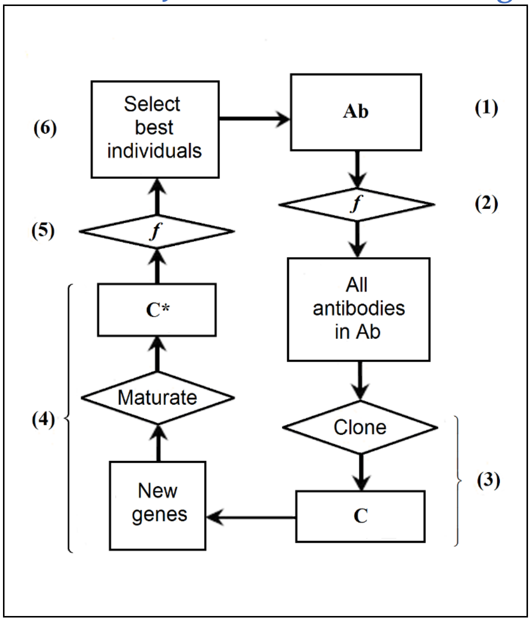

Figure 1. A diagram of the modified Clonalg (Eryiğit, 2015).

In order to optimize water resources allocation for the sectors two objective functions were considered, and both objective function were simultaneously maximized depending on each other. Maximum satisfaction of water demands of the sectors was aimed by first objective function (OF_1) while maximum economic benefit (income) was aimed by second objective function. (OF_2). OF_1 and OF_2 are expressed as follows (Babel et al., 2005):

$$OF_1 = \frac{1}{n}\sum_{i=1}^{n}\frac{S_{ai}}{D_{ni}} \tag{4}$$

where S_{ai} is a water allocated to sector i, D_{ni} is a normal water demand of sector i, and n is a total number of water demand sectors.

$$OF_2 = \left[\frac{\sum_{i=1}^{n} S_{ai}\cdot NER_i}{AW\cdot NER_{max}}\right] \tag{5}$$

where NER_i is a net economic return (income) per unit volume of water from sector i (USD/m^3), AW is an available water (total water amount, m^3), and NER_{max} is a maximum net economic return among the sectors (USD/m^3). The values of OF_1 and OF_2 are between 0 and 1.

The sum of OF_1 and OF_2 multiplied by the respective weights was maximized in this study. The sum of them (OF_{12}) is as the following (Babel et al., 2005):

$$OF_{12} = w_1\cdot OF_1 + w_2\cdot OF_2 \tag{6}$$

where w_1 and w_2 are the respective weights depending on a user. In this study, w_1 and w_2 were assigned as 1.

2.2 Application of the Optimization Model

The model was applied to a scenario regarding an allocation of water resources among 10 different sectors in order to test its performance. According to the scenario, there are ranges of minimum and maximum (or normal) water demands of the sectors, and unit economic benefit (income) of each sector. Total amount of water for the allocation was assumed as 300,000,000 m^3. Ranges of the water demands and unit benefits were as given in Table 1.

The optimization model was coded in Matlab R2014a programming software, and the PC having Intel I5 Core 2.5 Ghz Processor was used for the analyses. The model was run 100 times to obtain the maximum value of OF_{12} until a maximum number of iteration (IN) is reached in each run. A random number generation was performed during generating an initial set of water amounts allocated in each run.

Table 1. Ranges of the water demands and unit economic benefits of the sectors in the scenario.

Sector	Min. water demand (m^3)	Max. water demand (m^3)	Unit economic benefit (USD/m^3)
Drinking water	100,000,000	200,000,000	9
Environmental water	75,000,000	150,000,000	7
Agriculture	20,000,000	200,000,000	10
Industry	0	55,000,000	7.5
Energy	0	25,000,000	8.5
Mining	0	30,000,000	10.5
Livestock production	0	40,000,000	10
Aquaculture-Fisheries	0	50,000,000	1.5
Tourism	0	18,000,000	9
Commercial water	0	14,000,000	12

3. RESULTS

Range searching for the model was performed in the ranges of minimum and maximum water demands of the sectors (see Table 1) depending on OF_1 and OF_2 for optimum water allocation. Results of the water allocation for the sectors were given in Table 2.

Table 2. Results of optimal water allocation.

Sector	Allocated water (m^3)	Total allocated water (m^3)
Drinking water	100,000,000	299,999,999.9
Environmental water	75,000,000	
Agriculture	20,000,000	
Industry	0	
Energy	25,000,000	
Mining	30,000,000	

Livestock production	18,000,000
Aquaculture-Fisheries	0
Tourism	18,000,000
Commercial water	14,000,000

After running the model 100 times the best, fittest value for OF_{12} (f) value was found as 1.2945 by allocating minimum water demand values to the sectors of drinking water, environmental water, agriculture, industry and aquaculture-fisheries, while allocating maximum (normal) water demand values to the other sectors (energy, mining, tourism, commercial water) except livestock production (see Table 2 and 3). The range of water demands of drinking water, environmental water and agricultural irrigation sectors are very high. Therefore, the model selected the minimum water demand values of these sectors in order to allocate sufficient water to the other sectors for maximization of OF_1. On the other hand, the water was not allocated to the sectors of industry and aquaculture-fisheries, due to their lower unit economic benefits (7.5 and 1.5 USD/m^3) than energy, mining, livestock production, tourism and commercial water sectors. The model also allocated maximum water demands of the sectors of energy, mining, tourism and commercial water in order to maximize both OF_1 and OF_2. Furthermore, as all of the total water (300,000,000 m^3) could be allocated to the sectors, these results are reasonable.

Table 3. The modified Clonalg's parameters and performances in the application.

N_{Ab}	β	ρ	PR	IN	Max. OF_{12}	Max. OF_1	Max. OF_2	Run time (sec)
100	1	10	0.25	500	1.2945	0.555	0.7395	111.5

N_{Ab}: Population number. β: Coefficient of multiplying. ρ: Coefficient of decay. PR: Probability rate. IN: Iteration number.

4. CONCLUSION

The weight coefficients (w_1 and w_2) to be used in OF_{12} calculation selectable by the water resources planner. If the satisfaction of the water demands is aimed rather than the economic benefit, w_1 can be increased. In contrast, if the economic benefit is intended, then w_2 can be increased. In this study, both weight coefficients were selected equally. In case of changing the values of w_1 and w_2, the results of the water allocation might be different.

The results demonstrated that the model is useful and feasible in the water resources allocation and planning, and it can be used as an alternative to the other models in the literature. In future studies, the model may be tested under different water allocation conditions.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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