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Research Paper

An Imperialist Competitive Algorithm (ICA)-Based Approach to Optimize the Reservoir Storage of the Kahir Dam

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Abstract

Water scarcity, especially in Iran and during the recent droughts, emphasizes the importance of achieving an optimal operation policy for large dam reservoirs. In the last two decades, the annual optimization of dam reservoirs under controlled conditions, as well as climatic and real conditions, has attracted many researchers and experts. This study proposes a new approach to predict reservoir dam storage. The imperialist competitive algorithm (ICA) is a new approach in the field of evolutionary computation that calculates an optimal solution for different optimization problems. Using mathematical modeling of the social-psychological evolution process, ICA provides a new approach to solve mathematical optimization problems, and compared to other algorithms, it has appropriate speed and high convergence rate in finding an optimal answer. This research used the ICA for the annual optimization of the Kahir reservoir to derive optimal policies. Objective function downstream water issue needs to establish relationships based on continuity were selected. Comparison of ICA model in population 100 showed that the ICA algorithm with average best objective function value of 125, 114.6, and 85.60 with a number of further evaluations of the objective function to achieve higher capacity is the optimum answer. The results showed a 6.1 percent error in the implementation of the ICA algorithm between the observed and predicted storages. The results of applying the ICA to the annual optimization problem demonstrate the capability of the proposed method.

Keywords:
Optimal operation, imperialist competitive algorithm, prediction of reservoir dam storage, Kahir Dam

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INTRODUCTION

Water is one of the most valuable natural resources and a part of the national capital of each country (Mianabadi et al., 2015; Sardar Shahraki et al., 2018). Water is also an indispensable commodity for human survival. It is also considered a very rare source for production (Shahraki & Aliahmadi, 2014; Sardar Shahraki et al., 2016; Shahraki et al., 2012). The role of water resources has been very influential in economic, social, and cultural infrastructure and yet it has become much more important today due to the changing climate conditions and the phenomenon of drought (Safari et al., 2014). The world is faced with growing water scarcity and growing demand (Mourad & Alshihabi, 2016; Sardar Shahraki et al., 2016). In the modern view, water is a socioeconomic commodity and a primordial need of humans. Naming 2003 as the world watershed year highlights the importance of this issue in human life, the need to gain information about it, and the optimal and sustainable use of this valuable resource.

The optimal utilization of water is one of the most effective ways to cope with water scarcity. Therefore, increasing demands for water, the economic value of the optimal operation of water resource systems, and the declining quality of the available water resources have made the optimal operation of dam reservoirs one of the most important issues in the management of water resources (Arjoon et al., 2016). Undoubtedly, floods are known as a natural disaster, but they are practically considered to be an enormous natural disaster in terms of both casualties and financial losses. The present study focuses on how to optimize flood control storage of multi-purpose reservoir dams with the aim of minimizing flood damage and unsatisfied demands (Asl Rousta & Araghinejad, 2015). Demand is an important issue for reservoir management since it is used for environmental preservation, water supply, irrigation, and energy production. Several factors need to be considered in reservoir operations including inflow, outflow, elevation, and evaporation. Traditional operational systems for reservoirs might not reflect today's various demand parameters on reservoirs. The application of optimization theory to reservoir operations for planning purposes is an important research area that delivers the advantages of producing energy and maximizing economic benefits (Sardar Shahraki, 2016).

About 72 percent of the Earth's surface is covered with water, but 97 percent of these waters are salty and not drinkable. This is despite the fact that:

- 70 percent of the world's fresh water is in the form of ice caps in Arctica and Antarctica;
- Less than one percent of the world's fresh water is readily available;
- A lot of fresh water is stored in the form of underground water;
- Six countries (Brazil, Russia, Canada, Indonesia, China, and Colombia) account for about 50 percent of the world's freshwater resources;
- One-third of the world's population lives in countries with a severe shortage of water resources.

The existence of multiple consumers with different utility and priorities in the management and planning of water resources arises significant disagreements and tensions on water resources in the basin, and this has been a source of concern for managers and planners.

With the development of computers within the last 40 years, optimization techniques have increasingly been refined, especially for managing and operating complex reservoir systems. The literature shows that optimization techniques are a great help in solving various aspects of reservoir management systems. Nowadays, due to the diversity and complexity of the problems, the necessity of using modern optimization tools has been proved (Habibi Davijani et al., 2016). A lot of literature describes the use of dynamic programming (DP), linear programming (LP), nonlinear programming (NLP), and genetic algorithms (GA) for developing reservoir-operating and reservoir-storage rules in water management (Rafiee Anzab et al., 2016).

Iran is climatically located in the dry and semi-arid zone of the world. The average annual rainfall in Iran is 250 mm, which is much less than the average annual rainfall in Asia and the world (732 and 831 mm, respectively) (Reports of Iran Meteorological Organization, 2017). On the other hand, the average annual evaporation of water in the world is 700 mm, while it amounts to 2100 mm in Iran. At present, 135 billion m^3 of renewable water is annually consumed by 80 percent of the world's population, which illustrates the critical condition of water in Iran. Despite the severe water shortages, Iran is in the world's sixth place in terms of water consumption[1] (Iranian Ministry of Energy, 2014).

In terms of water resources in Iran, Sistan and Baluchestan province is in a worse condition than the average of the country and it has undergone successive droughts in recent years. The annual evaporation rate in the province is 4000 mm which is about 2 times as great as the average of the country. On the other hand, the average rainfall is about 70 mm which is much lower than the country's average. The Kahir Dam is located in the south of Sistan and Baluchestan province (Figure 1) and has an important role in water supply downstream. Therefore, it is quite necessary to optimally allocate the Kahir dam as one of the main dams in the south of this province. To achieve this objective, the imperialist competitive algorithm (ICA) is used. In particular, the research aims to study how to optimally allocate the water resources of the Kahir Dam by using the imperialist competitive algorithm (ICA).

There has been extensive research on modeling water resource management. Initially, the models were very simple, but they have grown in sophistication with scientific advances and computer software developments (Zhang et al., 2014). With the advancement in information technology, decision support systems have emerged as one of the ways to solve water management problems with conflicting goals. These systems are suitable computer programs that combine data, decision-making, and modeling solutions to solve water management problems and provide the right solution (Yang, 2009). The first is the classification of the models into dynamic and static. Static models can be used to explore the effects of a particular change in the system, while dynamic models are used to express the dependencies between variables within a system in different years or months. As a result, a dynamic model is used to check changes in a system over time. The second set of models is definitive and random models. Definitive models are models whose influential factors on the model's results are predictable and well-known. On the other hand, random models are used when there is little or no information on uncertainty in decision making. Water models are all random. The third is the distinction between single-objective and multi-objective models. Single-objective models are used when all goals can be expressed in one single unit. Finally, the last is the division of economic and engineering models. In engineering, the operation and implementation of irrigation and water supply systems are important, but in economic models, the goal is to assess the effects of different activities on human well-being. The watershed models that have been used in recent years have included both economic and engineering models.

Heuristic algorithms that are a kind of random algorithms are used to find an optimal solution. In general, optimization algorithms are divided into two categories of precise algorithms and approximate algorithms (Afshar, 2003). Accurate algorithms are capable of finding an optimal answer accurately, but they do not have enough performance issues and their execution time increases exponentially in proportion to the dimensions of the issues. Approximate algorithms are capable of finding good (near-optimal) solutions in a

[1] According to the IranianMinistry of Energy, water consumption in Iran is more than 3.5 times its global average

Figure 1. The location of the Kahir Dam in Sistan and Baluchestan Province, Iran

short time for difficult optimization problems. Approximate algorithms are also classified into three categories of heuristic, meta-heuristic, and hyper-heuristic algorithms. The two main problems of heuristic algorithms, catching them at local optimum points, are early integration into these points. Fractional algorithms are presented to solve these problems with heuristic algorithms. In fact, meta-heuristic algorithms are a kind of routine optimization algorithms that have solutions that outsource local optimal points and are capable of application in a wide range of issues. Various categories of this kind of algorithm have been developed in recent decades (Karamouz et al., 2014). In this regard, research is underway on metamorphosed algorithms for water resources management, which are reviewed below.

Afshar et al. (2014) developed a set of optimal rule curves for the operation of a single reservoir system for water supply and hydropower generation using the ICA and the ant colony algorithm in a simulation-optimization model. The results suggested the better performance of the ICA. Karamouz et al. (2014) proposed a model for the optimal operation of the Karkheh dam reservoir, considering the factors such as the benefits and authority of the stakeholders of water resources. This model was formulated using conflict resolution theory and AHP. The ICA and particle swarm optimization (PSO) algorithm were used to derive the optimized reservoir releases in each period. The criteria such as reliability, resiliency, and vulnerability were used to evaluate the capability of the proposed models, which suggested a higher efficiency of ICA than PSO.

A significant point in past research is that despite utilizing hybrid optimization techniques in recent years and such methods as the fuzzy method, the genetic algorithm, and the PSO algorithm, this research is more of its initial application in dealing with water resource issues has been dealt with less in relation to the performance of dam reservoir.

It can be seen in the literature that many heuristic methods have been used to optimize reservoir-operating and reservoir storage systems, but there are no studies on the application of the ICA, even though it is computationally efficient and it has advantages of not being trapped on local optima. Thus, this study proposes the ICA for optimizing a reservoir storage system in an example reservoir. At first, the water management parameters such as water elevation level at storage, water losses, inflow, and outflow are set up with the sequential stream flow routing method. The ICA is applied to improve the performance of the Kahir Dam. The main objective of the study was to develop an optimal operation rule for the Kahir Dam for energy production.

METHODOLOGY

In this study, we use a new evolutionary optimization algorithm for data clustering inspired by imperialistic competition. ICA is a new socio-politically algorithm motivated by a global search strategy that was introduced to deal with different optimization tasks. This algorithm has shown great performance in both convergence rate and global optimal achievement, so this paper uses it. In ICA, each individual in the population is called a country, and the initial population is composed of these countries (imperialists and their colonies). ICA formulates the solution space of the problem as a search space.

Similar to other evolutionary algorithms (EAs), this algorithm starts with an initial population. Each individual in this population is called a country (in genetic algorithm, individuals in the population are called chromosomes). Some of the best countries (in this case, countries with the least cost value; for example, in data clustering the individuals with the lowest KHM objective value) are selected to be the imperialist states, and the rest of the individuals form the colonies of these imperialists. All the colonies of the initial countries are divided among the imperialists based on their total power. The imperialist states and their colonies form some empires. After forming initial empires, the assimilation policy is applied to the colonies in each of the empires and starts moving toward their relevant imperialist country. All empires try to take the ownership of colonies of other empires and control them. The imperialistic competition gradually provides a decrease in the power of weaker empires and an increase in the power of more powerful ones. In the basic version of ICA, the imperialistic competition is modeled by just picking some of the weakest colonies of the weakest empire and making a competition among all empires to possess these colonies. Assimilation policy and imperialist competition are the most important and basic operators in the ICA. The flowchart of the proposed algorithm is shown in Figure 2.

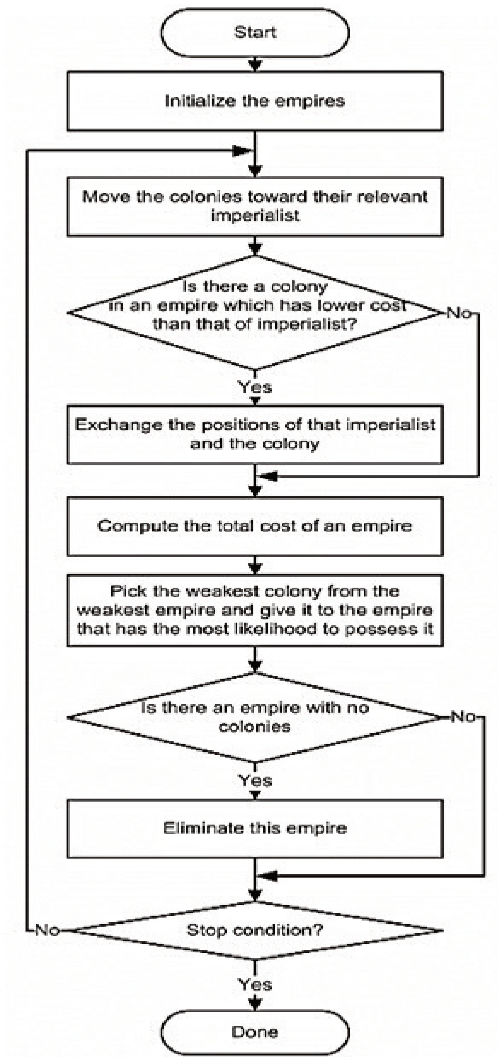

Figure. 2. The flowchart of the proposed algorithm

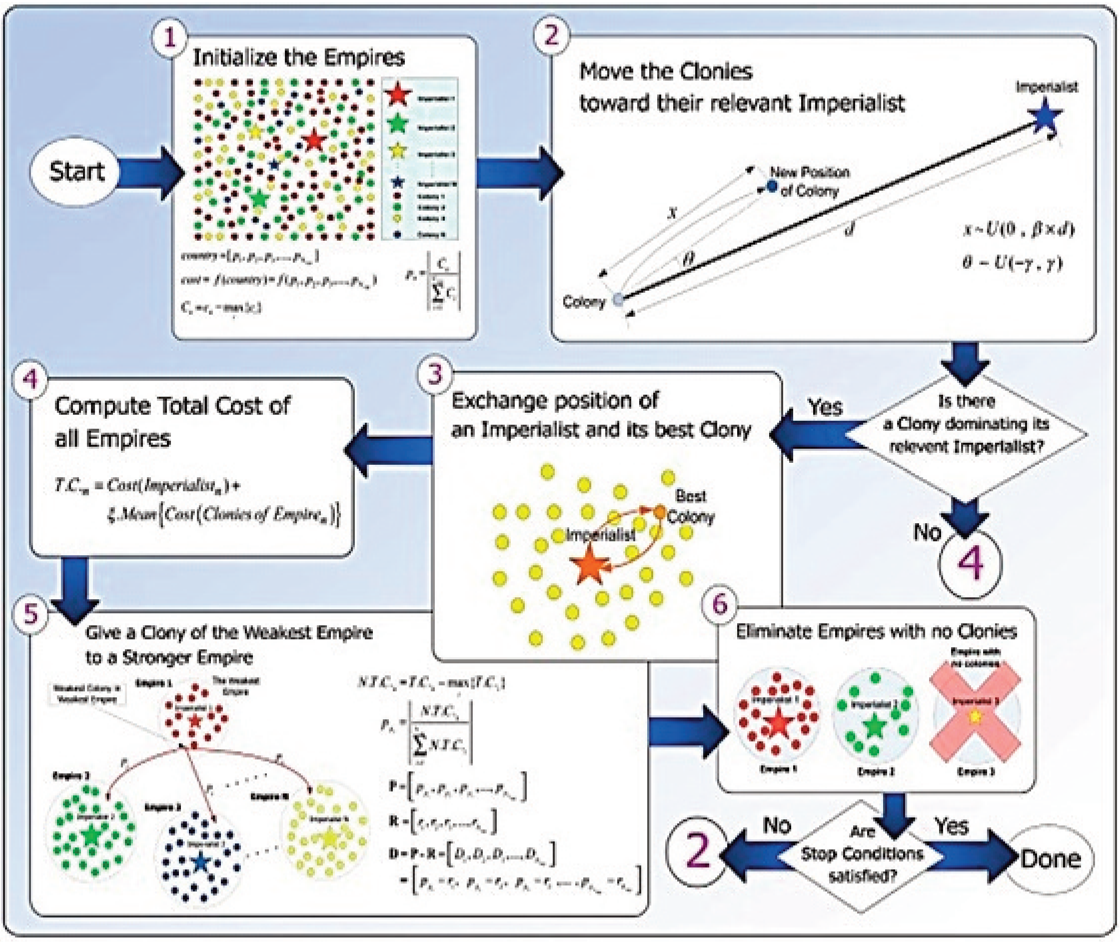

Figure 3. Modeling the ICA and its steps

The steps to perform the ICA algorithm are shown in Figure 3.

The studied area: Kahir Dam

To evaluate the efficiency of the proposed model in determining the optimal operation policies and predicting the reservoir storage, the information of the Kahir dam, located in Sistan and Balouchestan province, 110 km from Chabahar city and 5 km north of Kahir village, was utilized. The dam is built on the Kahir River, which is from the Baluchistan Rivers, to supply agricultural and drinking water with an adjustable water level of 55 million m^3. The construction of the dam started in 2010 and will continue until this year (2017).

Table 1
Specifications of the Kahir Dam

Type of Dam	Roller-compacted Concrete (RCC)
Height from the foundation	54.5 m
Height from the bed	39.5 m
Width (crest)	382.5 m
Dam Body Volume	0.51 MCM
Normal capacity	314 MCM
Nominal capacity	167 MCM

In the present study, the fitness function of the ICA model minimizes the squared deviation of monthly irrigation demand and squared deviation in mass balance equation (1 to 4):

$$\text{Minimize} \quad F = (R_t - D_t)^2 + (S_t - S_{t+1} + I_t - R_t - E_t)^2 \tag{1}$$

Subject to:

$$S_{j+1} - S_j = I_j + D_j - E_j - R_j \tag{2}$$

$$j = 1, 2, ... 167 \tag{3}$$

$$x_{min} \le x_k \le x_{max} \quad ,k=1,2,...,12 \tag{4}$$

$$s_{min} \le s_k \le s_{max} \quad ,k=1,2,...,12$$

$$Q_{1min} \le Q_1 \le Q_{1,max} \qquad Q_{2min} \le Q_2 \le Q_{2,max} \tag{5}$$

Release constraint

The irrigation release in any month should be less than or equal to the irrigation demand in that month and this constraint is given by:

$$R_t = D_t \qquad t = 1, 2, 3, ..., 12 \tag{6}$$

Storage Constraint: The reservoir storage in any month should be no more than the capacity of the reservoir and should be no less than the dead storage. Mathematically, this constraint is expressed as:

$$S_{min} = S_t, \; S_t = S_{max} \qquad t = 1, 2, 3, ..., 12 \tag{7}$$

where:

S_{min} is the dead storage of the reservoir in MCM and S_{max} is the maximum capacity of the reservoir in MCM.

Over flow constraint:

When the final storage in any month exceeds the capacity of the reservoir the constraint is given by:

$$Q_t = S_{t+1} - S_{max} \qquad t = 1, 2, 3, ..., 12 \tag{8}$$

$$Q_t = 0 \qquad t = 1, 2, 3, ..., 12 \tag{9}$$

where:

Q_t is the surplus from the reservoir during the month *t*. In above equations, *F* is the objective function that is to be optimized as dam reservoir storage, *j* is an index that refers to data over a period of one month, x_{min} and x_{max} express the minimum and maximum reservoir operation levels, S_{j+1} indicates the real storage volume at the end of the period, S_j denotes the storage volume at the beginning of the period, and I_t, D_t, E_t, and R_t represent monthly inflow, precipitation, evaporation, and real release volumes at the end of each period, respectively. *K* is an index that represents the months within the year, x_k is the target reservoir operation level (m), and Q_{1min} and Q_{2min} are the minimum discharge rates for the turbines. The values of Q_{1max} and Q_{2max} identify the maximum discharge rates for the turbines. The values of Q_1 and Q_2 express the estimated discharge rates for turbines. Eq. (1) represents the continuity equation, while Eq. (2) is the constraints.

The above fitness function of the ICA model is subjected to the up constraints and bounds.

RESULTS AND DISCUSSION

After introducing the objective function, performing a sensitivity analysis to find the optimal values of the effective parameters of the algorithm, and implementing the model, the decision variables of the problem, including 24 variables, were calculated. In the ICA formulation, 12 decision variables in the case study were each represented by substring representing 12 possible alternatives. The maximum values of the objective function after 94 colonies achieved with gold value are presented in Figure 3.

The ICA parameters are presented in Table 2.

Table 2
Parameters Used to Run ICA

Parameter	Value
The number of initial countries	100
The number of initial colonists	6
The number of colonies	100-6=94
β	2
γ	π/4
ζ	0.01

In Table 2, β is a number greater than 1. A $\beta>1$ causes the colonies to get closer to the imperialist state from both sides. γ is a parameter that adjusts the deviation from the original direction. Nevertheless, the values of β and γ are arbitrary. In most of our implementations, a value of about 2 for β and about $\pi/4$ (Rad) for γ have resulted in good convergence of countries to the global minimum, and ξ is a positive number which is considered to be less than 1. A small value for ξ causes the total power of the empire to be determined by just the imperialist and increasing it will increase the role of the colonies in determining the total power of an empire. We have used the value of *0.01* for ξ in most of our implementations.

Figure 4 shows the amount of storage applying to the implementation of the algorithm which is very close to the measured value of the dam storage and it proves the convergence, ability, and accuracy of the ICA rivalry in water resources systems.

Table 3 presents the results of the ICA for the Kahir Dam in different months of the year.

The result showed the amount of storage applied to the implementation of the algorithm which is very close to the measured value dam storage.

The percent of error between the measured data and the results of the calculation for the implementation of ICA is shown in Figure 5.

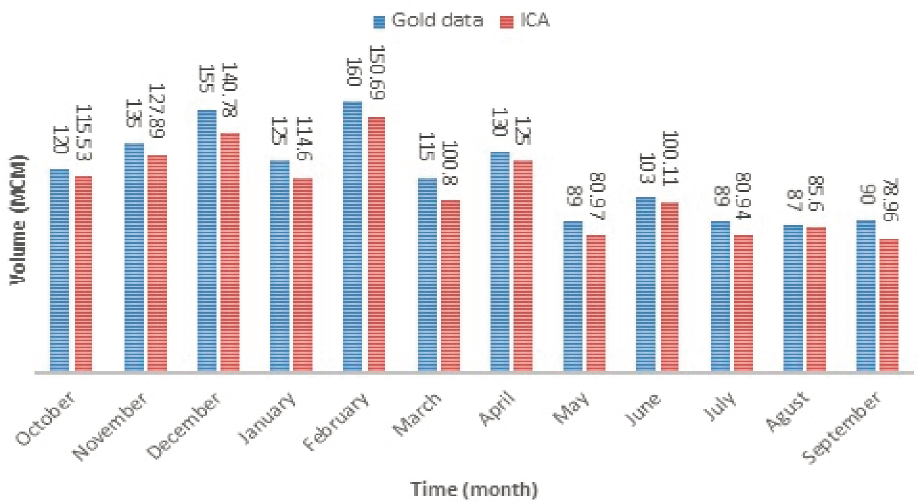

Figure 4. Comparing the amount of real reservoir storage and the value calculated by ICA

Table 3

The Results of the ICA for the Kahir Dam

Optimized storage volume of the model (ICA)(MCM)	Optimum output volume of the model (ICA)(MCM)	Month
115.53	28.1	October
127.89	22.12	November
140.78	45.8	December
114.6	32.5	January
150.69	24.8	February
100.8	22.6	March
125	70.56	April
80.97	20.68	May
100.11	47.2	June
80.94	35.5	July
85.6	30.9	August
78.96	36.4	September

Figure 5. Comparing the storage value in different months

The compliance rate for the entire 12 month periods shows monthly output operation of the reservoir in Figure 6 both diagrams are coincident perfectly with downstream irrigation demand.

Figure 6 shows the convergence trend of the total deficiency for the 12 months of the operation period based on the best-obtained population from the operating model. (The number of stages of the implementation: 3000 and the initial population: 100.) As shown in Figure 7, the deficiency of the operation policy, which is provided by the ICA, is significantly lower.

As one can see, the results of the ICA are satisfactory. Firstly because, as can be inferred from the graph reservoir capacity determined approximately. Secondly, as it can be seen downstream irrigation demand are supplied with a high percentage.

Verification can be noted in Figure 8, which illustrates the charts and the outflows from the dam downstream irrigation demand. It can be seen that the two curves consider, as well as has been blocked much downstream irrigation demand and the waste of water.

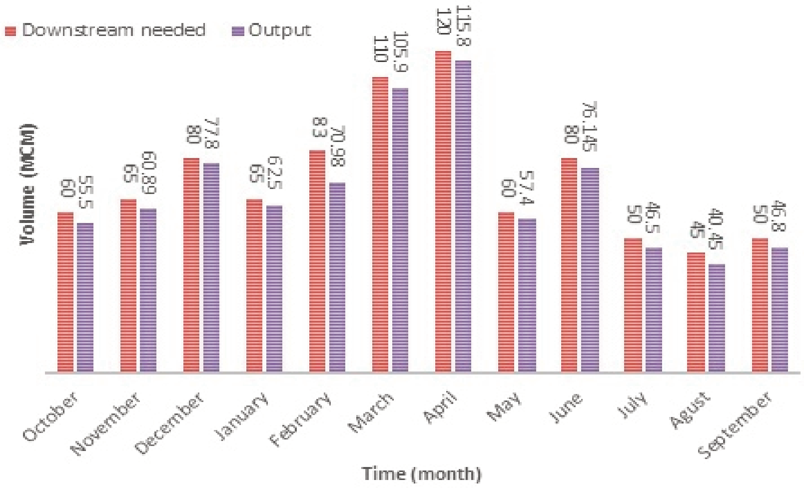

Figure 6. The compliance rate for the entire 12 month period, shows monthly output operation of the reservoir

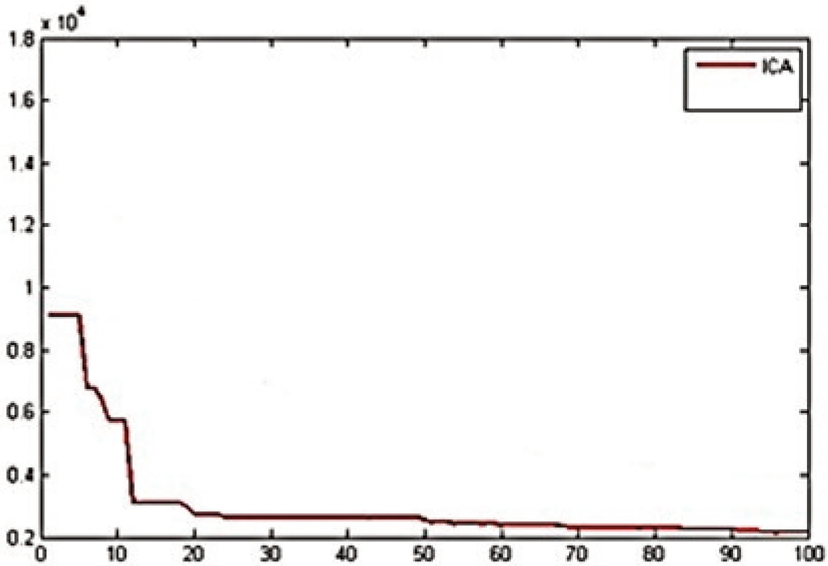

Figure 7. The convergence trend of the total deficiency for the 12 months from the ICA code

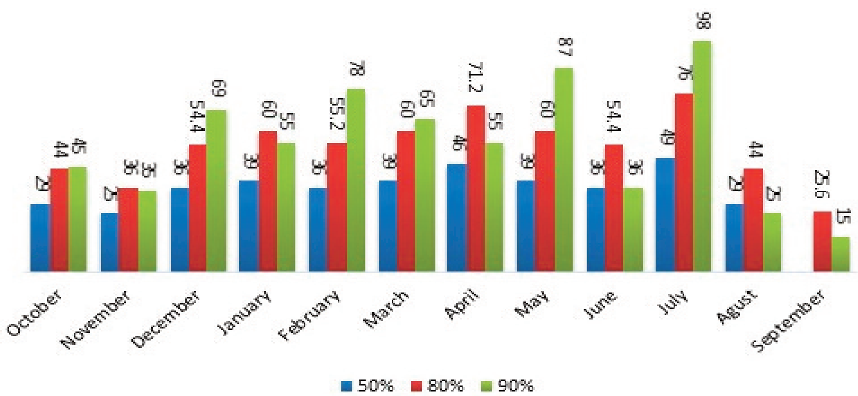

Figure 8. The process of adaptation downstream required of the dam and the output value Ccalculated by the ICA model

CONCLUSIONS AND SUGGESTIONS

A methodology for the application of the ICA method to reservoir optimal operation has been presented in this paper, and the prediction and special values have been compared. This algorithm has a high convergence rate and can find global extremes in optimization problems. It has been proved that ICA can be successfully used in reservoir storage, which indicates that there is potential for the application of ICA to multi-reservoir system problems.

The results showed that the proposed model (ICA) is very optimal in predicting reservoir dam storage with high speed, accuracy, and convergence in finding the optimal solution. In the studied system, the initial population was 100, and the selection of a uniform distribution leads to the best results. The results also show a 6.1 Percent error in the implementation of the ICA between the observed and predicted storages. Generally speaking, the results of this research proves the superiority of the ICA in terms of efficiency and high convergence rate in predicting the storage of dam reservoirs. According to the results, the following policy suggestions can be made:

Meta-heuristic algorithms, including the colonial competition algorithm for optimal water allocation, the ability to create an appropriate decision environment and the context. Provides different management scenarios, therefore, to water allocation administrators at the district level, it is recommended to manage and optimize the operation of reservoir dams and other water resources to consider these methods.

By interviewing the relevant experts, it became clear that a program for exploitation, Due to the critical conditions of water in the studied area. Therefore, it is suggested that policies, long-term strategies, and future plans on allocation and exploitation of water, according to the current situation in the region.

There are unauthorized water withdrawals in the agricultural sector in the studied area which disturbs the supply and demand balance of the water. Water planners should pay close attention to this issue so that water resources in the region are allocated optimally.

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