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OPTIMIZATION OF HARAZ DAM RESERVOIR OPERATION USING CBO METAHEURISTIC ALGORITHM

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ABSTRACT

Optimization has always been a human concern from ancient times to the present day, also in light of advances in computing equipment and systems, optimization techniques have become increasingly important in different applications. The role of metaheuristic algorithms in optimizing and solving engineering problems is expanding every day, optimization has also had many applications in water engineering. Every year, the effects of climate change and the water crisis deepen and worsen in many parts of the world, and existing water management becomes much more vital and critical. One of the main centers for water management and control dams reservoirs. In this paper, applying the CBO metaheuristic algorithm, the results of optimization in the operation of the Haraz dam reservoir in northern Iran, which has previously been done with FA and GA algorithms and standard operation system (SOP), are reviewed and compared. With the implementation of the CBO algorithm, all results and key outputs such as program runtime, annual water shortages, and vulnerabilities are much better than previous calculations, all the results are mentioned in the text of the article, but for example, the annual water shortage has reached about 38% of the FA algorithm, about 25% of the GA algorithm and about 13% of the SOP method. The numerical results demonstrate that the CBO algorithm has merits in solving challenging optimization problems and using this innovative algorithm can be an important starting point in the operation of dam reservoirs around the world.

Keywords: Haraz dam; metaheuristic algorithm; CBO algorithm; reservoir optimization; FA algorithm; GA algorithm.

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1. INTRODUCTION

Limiting water resources and increasing water demand due to global population growth,

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urban development, changes in public welfare, and unprincipled use of this vital fluid have caused many problems in most parts of the world. This problem is expected to create new and larger challenges in local, regional, and global dimensions shortly and differences between people in countries with water stress will deepen and intensify in the coming years and will affect and further transform the friendly relations between the countries. The important topic of optimization can be used in all parts of water engineering sciences, one of the most important points of control and optimization of water resources in any country are dams. Previously, proper and optimal planning of reservoirs and creating a balance between inlet water and downstream needs was done by traditional methods, but, with the advent of computer systems and optimization programs, the operation of dam reservoirs was done by metaheuristic algorithms metaheuristic methods caused a change and revolution in the field of optimization. Metaheuristic algorithms are a recent generation of optimization approaches to solve complex problems. These methods do not depend on the type of problem in terms of linearity and nonlinearity, they have the appropriate speed and accuracy compared to other available methods. This article was reviewed by Rani and Moreira in 2010, [1]. This knowledge has entered a new field with the publication of several articles on the appropriate responses of metaheuristic algorithms in regulating reservoir water release, many scientific journals have approved and published many articles on reservoir optimization with metaheuristic algorithms, this trend has grown significantly in recent years.

The famous British journal "Advances in Water Resources" in many of its articles has addressed the importance of the role of algorithms in the operation of dam reservoirs, one of those articles is a comparison of reservoir operation optimization methods, which was published in 2019 by Barnaby Dobson et al., [2]. The journal "Hydrology", which is a scientific journal in the Netherlands, also has many articles on the use of algorithms in reservoir optimization. one of them is the use of the M.S. optimization algorithm to improve the reservoir operation policy, published in 2019 by Turgat et al., [3]. Manatwy et al. In 2003, [4] and Khademi et al. In 2011, [5] used the simulated annealing algorithm for optimal reservoir operation, which checked the results of the proper performance of the algorithm. Karaboga et al. In 2008, [6] used the forbidden search algorithm to evaluate the optimal output performance of reservoir overflows. Bani Bashar et al. In 2010, [7] and Afshar et al. In 2011, [8] used the ant community algorithm in the optimal use of reservoirs and reported its performance as appropriate. Janat Rostami et al. In 2010, [9] used the harmonic search algorithm to manage the operation of reservoir dams. In 2010, Bozorg Haddad et al., [10] used the bee mating algorithm to optimally exploit the reservoir. Hall and Esat in 1994, [11] used the genetic algorithm to optimize the operation of the four-reservoir system. Oliveira and Loucks in 1997, [12] used a genetic algorithm to extract the rules of reservoir operation. Reddy and Kumar in 2007, [13] used the particle cluster optimization algorithm to optimize the multi-objective reservoir. In 2012, Ostadrahimi et al., [14] used the particle cluster optimization algorithm to extract the rules of operation of a multi-reservoir system.

Also, a three-reservoir system with different objectives of hydropower generation, supply of downstream needs (agricultural, urban and industrial), and flood control in 2014 was presented by Seifollahi Aghmioni and Haddad, studies have shown that the results of the research are completely consistent with reality and the algorithm can show the performance of the reservoir system well in single-reservoir or multi-reservoir, single-objective or multi-objective modes, [15]. In a 2011 study in Thailand, Divakar et al., [16] proposed a model for optimally allocating water to four sectors: agriculture, household, industry, and hydropower, intending to maximize net economic benefits for the Chao Faria River Basin, this model can improve economic profitability compared to the old methods of water allocation. Chang et al. In 2013, [17] used a hybrid model of two algorithms to minimize water scarcity and generate maximum power from the Tao River water resources. One of the most recent articles on combining two algorithms for optimization is related to the research of Davood Sedaghat Shaygan et al. in 2020 with the combination of two algorithms CBO and MBF, from which acceptable results have been obtained, [18], In 2019, Davood Sedaghat Shaygan et al. also published an article entitled mouthbrooding fish algorithm for cost optimization of reinforced concrete one-way ribbed slabs, [19] in "international journal of optimization in civil engineering" (IJOCE).

Another example of research that is the basis of this article is the article of Eassa Kia et al., which was published in 2018 under the title "Efficiency of different optimization methods in the operation of Haraz Dam reservoir" and in which the FA metaheuristic algorithm is compared with the GA algorithm and the standard reservoir operation method (SOP), which shows The FA metaheuristic algorithm has superior results than the other two options, namely GA algorithm and SOP method, [20]. Considering the political, economic, and social importance of Haraz Dam in the north of Iran and its role in the optimal management of downstream water needs, we maintain all the hypotheses and results of the article "Efficiency of different optimization methods in the operation of Haraz Dam reservoir", and continue the optimization path by implementing the CBO metaheuristic algorithm and compare its results with all the outputs of the FA and GA algorithms and the standard reservoir operation method (SOP). It is predicted that the results of the implementation of the CBO algorithm will be better than the results of the traditional operation method, but the results of the implementation of the three algorithms CBO, GA, and FA are interesting and should be studied and analyzed. In this research, all the presuppositions, information, and constraints contained in the Haraz Dam article are written and run in MATLAB program with CBO algorithm code then the results of the objective function, run time, annual water shortage, and vulnerabilities will be compared with the old results obtained from the FA and GA algorithms and the SOP method. The use of the CBO metaheuristic algorithm is based on the famous article by Dr. Kaveh and Mahdavi, published in 2014 in the journal Structures and Computers, [21]. Actually after 2014, the use of CBO became popular in several articles, some of which are mentioned below:

Kaveh and Mahdavi in an article entitled Colliding Bodies Optimization method for optimum discrete design of truss structures, which was published in 2014 applied CBO for the optimization of truss structures with discrete sizing variables, [22]. Kaveh and Ilchi Ghazaan in 2015 with the publication of an article entitled A comparative study of CBO and ECBO for optimal design of skeletal structures, compared the capability of the CBO and ECBO through two trusses and two frames structures, [23]. Kaveh and Mahdavi also published an article in 2015 in Advances in Engineering Software magazine entitled Two-dimensional colliding bodies algorithm for optimal design of truss structures and explain about two dimensional CBO and its utility for the optimization of truss structures, [24]. As well as, Kaveh, Maniat and Arab Naeini in 2016 in an article entitled Cost optimum design of post-tensioned concrete bridges using a modified colliding bodies optimization algorithm, by modifying the CBO algorithm optimized cost design of concrete bridges, [25]. In 2021

Kaveh, Kamalinejad, Arzani and Barzinpour by publishing an article in the Journal of Building Engineering entitled New enhanced colliding body optimization algorithm based on a novel strategy for exploration, explained the difference between CBO, ECBO and NECBO and the capabilities of NECBO in optimization, [26].

In the rest of this article, we will briefly address the important issue of optimization problem formulation, then we talk about the CBO metaheuristic algorithm and its functional concept, after it the most important part of the article is presented, in numerical example, we explain concept of dams operation and Specifications of the Haraz Dam and the research that has been done to compare the FA and GA algorithms and the SOP method in its operation, [20] then we will talk about our work, the results of implementing the CBO algorithm in the MATLAB program and compare old result [20] to our new result for optimization of Haraz dam operation. Finally, we will have a conclusion and then present the references.

2. FORMULATION OF OPTIMIZATION PROBLEM

Optimization algorithms that have helped solve many engineering problems are used to obtain the minimum or maximum value of objective functions under some specific limitations. The formulation of metaheuristic algorithms is often inspired by natural phenomena or physical laws, applying an optimization algorithm, should be cast as an explicit mathematical optimization formulation. There are different types of optimization algorithms, Optimization algorithms for solving problems are divided into multi-objective and mono-objective functions. In most cases, to simplify and solve the problem, it is assumed to be a mono-objective and the problem is solved by defining the penalty function. The mono-objective optimization problem can be shown with relations number 1 and 2:

$$\begin{gathered} \text{Find } X=[x_1.x_2.\ldots.x_n] \text{ To minimize } Mer(X) \\ \text{Subjected to:} \\ g_j(X)\leq 0\ ,\ \text{j=1, 2,…,m} \\ x_{imin}\leq x_i\leq x_{imax} \end{gathered} \tag{1}$$

X: vector of all design variables with n unknowns
Mer (X): objective functions
g_j is the jth constraint from m inequality constraints
x_{imin} and x_{imax}: The lower and upper bounds of design variable vector
The merit function which should be minimized is defined as:

$$\mathrm{Mer(X)} = \mathrm{F(X)} \times \mathrm{f}_{penalty}(\mathrm{X}) = \mathrm{F(X)} \times \left(1+\gamma\times\sum_{k=1}^{m}\max\big(0.\mathrm{g(X)}\big)\right) \tag{2}$$

Mer(X): Merit function
F(X): objective function

γ: Penalty parameter
$f_{penalty}$ (X): Penalty function

3. COLLIDING BODIES OPTIMIZATION (CBO)

CBO (Colliding Bodie's optimization) algorithm is a metaheuristic algorithm that was defined in 2014 by Kaveh and Mahdavi, [21] and with the publication of Article computer codes for colliding bodies optimization and its enhanced version in 2014 in "international journal of optimization in civil engineering" (IJOCE), it was developed by Messrs. Kaveh and Ilchi Ghazaan, [27]. The invention of this algorithm is inspired by the collision of objects that move relative to each other with the least energy level after the collision. The CBO algorithm has a simple concept and, unlike most metaheuristic algorithms, does not depend on any internal parameters. In principle, the important advantage of this algorithm is that there is no need to adjust internal parameters and use simple formulation and complete understanding of it, Given the favorable results of the CBO algorithm, the willingness of researchers to use this algorithm will increase in the coming years.

In this algorithm, one object collides with another, and objects move or change in such a way that energy is minimized, each object that hits (Xi) has a specific mass, in other words, a specific mass is assigned to it, which is determined based on relation number 3:

$$M_k = (1/ fit(k)) / (1/\sum (1/ fit(i))) \quad (\sum: i = 1: n) \;,\; k = 1,2,3,\ldots,n \tag{3}$$

In this formula, fit i represents the value of the objective function of the beating object i, and n is the number of striking objects. To select a pair of objects to collide, beating objects are classified in descending order based on the mass assigned to them and then they are classified into two categories according to Fig. 1:

1. Stationary group
2. Moving group

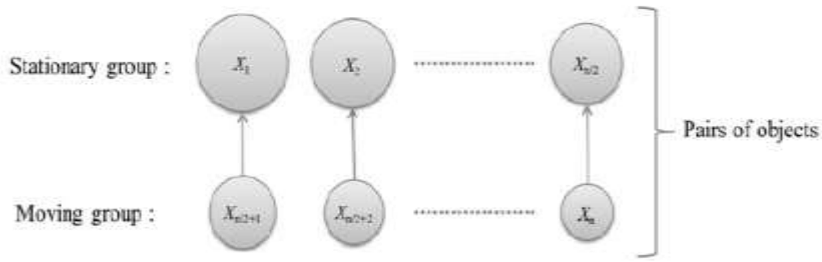

Figure 1. Division of colliding objects [27]

Moving objects hit stationary objects to improve their position and move stationary objects to a better position. The formulas and relationships related to this algorithm are detailed in the reference article [21], so it is omitted to mention it again. The flowchart of the CBO algorithm is shown in Fig. 2.

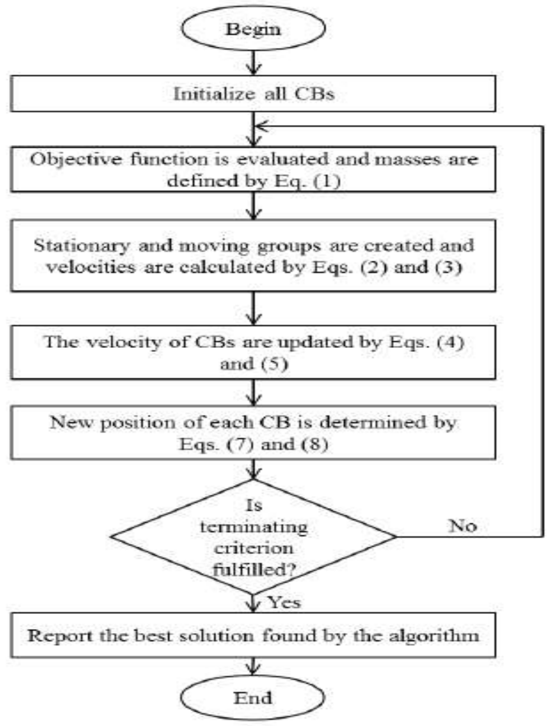

Figure 2. Flowchart of the CBO algorithm [27]

4. NUMERICAL EXAMPLE

The most important principle in the operation of reservoirs is to minimize the lack of water downstream of the dam, in this way, by carefully examining and analyzing the amount of water inflow and outflow from the reservoir and also the downstream needs, water shortage will be minimized. In this paper, the same functions and values, and coefficients of the Haraz Dam article, [20] are used, so that it is possible to accurately compare new and old results. The objective function is defined as the sum of the squares of the relative deficiencies in the allocation to it each month during the operation period and is given in Equation No.4:

$$\text{Min } F = (1/n) \sum ((De_t - Re_t)/D_{max})^2 \quad (\sum: t=1: n) \tag{4}$$

F: Objective function in allocation
n: length of operation
De_t: The volume required in the month t
Re_t: Volume of withdrawal from the reservoir in the month t
D_{max}: Maximum volume required during operation
The reservoir continuity equation is given in Equation No. 5:

$$S_{t+1} = S_t + Q_t + P_t - EV_t - Re_t - Sp_t \quad (5)$$

Inlet and outlet water limitations and restrictions are also given concerning numbers 6 to 11:

$$0 \leq Re_t \leq De_t \quad (6)$$

$$S_{min} \leq S_t \leq S_{max} \quad (7)$$

$$\begin{array}{c} Sp_t = S_t + Q_t + P_t - EV_t - Re_t - S_{max} \\ \text{If } S_t + Q_t + P_t - Ev_t - Re_t > S_{max} \\ Sp_t = 0 \\ \text{If } S_t + Q_t + P_t - Ev_t - Re_t \leq S_{max} \end{array} \quad (8)$$

$$\begin{array}{c} Re\ t = S\ t + Q\ t - Loss\ t \\ \text{If } S\ t + Q\ t - Loss\ t \leq R\ max \\ Re_t = R_{max} \\ \text{If } R_{max} \leq S_t + Q_t - Loss_t \leq S_{max} \\ Re_t = S_t + Q_t - S_{max} \\ \text{If } S_t + Q_t - Loss_t - R_{max} \geq S_{max} \end{array} \quad (9)$$

$$Loss_t = A_t \times (Ev_t - R_t) \quad (10)$$

$$A_t = a + b \times S_t + c * S_t^2 \quad (11)$$

S_{t+1}: Dam reservoir volume at the end of period t

S_t: Dam reservoir volume at the beginning of period t

Q_t: The volume of the inflow to the dam reservoir during period t

Sp_t: The volume of overflow from the dam reservoir during period t

Ev_t: Evaporation volume from the dam reservoir surface in period t

P_t: The volume of precipitation on the surface of the dam reservoir in period t

$Loss_t$: The amount of dam reservoir losses in period t

S_{max}: The Maximum volume of the dam reservoir

$S_{min:}$ The minimum volume of the dam reservoir

Using relations two to eight, the optimal operation policy of the dam reservoir is determined.

In optimal reservoir planning, we consider two penalties for reservoir volume and withdrawal volume and apply them to the objective function, since both the objective function and the penalty function must be minimized, the new objective function is given in Equation No. 12:

$$\begin{array}{c} \text{Min } F = (1/n) \sum ((De_t - Re_t)/D_{max})^2 + Pen\ 1 + Pen\ 2 \\ (\sum: t = 1: n) \end{array} \quad (12)$$

Penalties are defined in relations numbers 13 and 14:

$$\begin{array}{c} Pen\ 1 = D \times (S_{min} - S_t) / S_{min} \\ \text{If } S_t < S_{min} \\ Pen\ 1 = D \times (S_t - S_{max}) / S_{max} \\ \text{If } S_t > S_{max} \end{array} \quad (13)$$

$$Pen\ 2 = E \times (Re_t - De_{min\ t}) / De_{min\ t} \quad \text{If } Re_t < De_{min\ t}$$
$$Pen\ 2 = E \times (Re_t - De_{max\ t}) / De_{max\ t} \quad \text{If } Re_t > De_{max\ t} \qquad (14)$$

Pen 1: Penalty function related to dam reservoir volume

Pen 2: Penalty function related to release from the dam reservoir

$De_{max\ t}$: Maximum downstream needs in period t

$De_{min\ t}$: Minimum downstream needs in period t

To compare the performance of different algorithms in optimizing reservoir operation, the indicators of program run time, objective function value, annual water shortage, and vulnerability index will be used. The vulnerability index is obtained from Equation No. 15.

$$Vul = Max_{(t=1:T)} (De_t - Re_t) / De_t \quad \text{Till: } De_t > Re_t \qquad (12)$$

In this section the results of the CBO algorithm are compared with the results of FA and GA algorithms and the SOP method in optimizing the operation of the Haraz dam reservoir, the results of FA and GA algorithms and SOP method are presented in "Efficiency of different optimization methods in the operation of Haraz Dam reservoir", [20]. Haraz river originates from the Alborz mountains in the north of Iran, Haraz Dam is located downstream of Lar Dam on the Haraz River and is 20 km away from Amol city in Mazandaran province. This is a gravel earth-fill dam, its crest length is about 377 meters and the height of the dam is 150 meters, the volume of the dam body is about six million cubic meters and its reservoir volume is about 230 million cubic meters. With the construction and operation of this dam, downstream water needs for drinking, agriculture and industry will be regulated and released, of course, environmental water will be released at all times. For modeling, the average monthly flow rate of 27 years of river discharge, evaporation, and rainfall in the dam reservoir area will be used, [20], this statistic is given in Table No.1. Also, the water demand downstream of the dam in agriculture, drinking, industry, and environment is according to Table NO.2:

Table 1: Average statistics of rainfall, evaporation, and discharge of river inlet to Haraz dam reservoir based on Iranian months (million cubic meters), [20]

Total	**Shahrivar**	**Mordad**	**Tir**	**Khordad**	**Ordibehesht**	**Farvardin**	**Esfand**	**Bahman**	**Dey**	**Azar**	**Aban**	**Mehr**	**Upstream**
632	**38.8**	**47.3**	**71.8**	**110.3**	**118.4**	**66.9**	**33.3**	**26.4**	**26.5**	**28.9**	**30.9**	**32.5**	**Average monthly river discharge**
840	**86.6**	**42.2**	**46.1**	**34.8**	**42.9**	**50.3**	**70.5**	**72.4**	**74.7**	**100.9**	**104.3**	**114.5**	**Rainfall**
1034.2	**109.8**	**140.1**	**150.8**	**141.0**	**117.3**	**83.8**	**55.9**	**39.1**	**34.0**	**31.8**	**50.7**	**79.9**	**Evaporation**

Table 2: Downstream needs of Haraz Dam based on Iranian months (million cubic meters), [20]

Total	Shahrivar	Mordad	Tir	Khordad	Ordibehesht	Farvardin	Esfand	Bahman	Dey	Azar	Aban	Mehr	Downstream
528.8	**33.4**	**38.1**	**53.6**	**80.1**	**82.9**	**46.4**	**32.1**	**29.5**	**30.8**	**34.2**	**34.5**	**33.2**	**Environment**
1051.9	**1.5**	**152.3**	**214.6**	**216.4**	**268.0**	**199.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**Agriculture**
115.4	**9.8**	**9.8**	**9.8**	**9.8**	**9.8**	**9.8**	**9.1**	**9.5**	**9.5**	**9.5**	**9.5**	**9.5**	**Drinking and industry**
1696.1	**44.7**	**200.2**	**278.0**	**306.3**	**360.7**	**255.3**	**41.2**	**39.0**	**40.3**	**43.7**	**44.0**	**42.7**	**Total**

The results of FA and GA algorithms were obtained which are shown together with the results of the SOP method in Table No. 3, [20], according to the research, the results of the FA algorithm are better than the results of the GA algorithm and the SOP method [20]. In our paper to calculate the results by the CBO algorithm we keeping all the assumptions of the reference paper and with the Running of MATLAB program, the results of fourth row of Table No. 3 were obtained. Optimal parameters of CBO algorithm we have been used in the running of the program are population size and Iteration, these parameters are determined with Trial and error. Population size assumed 200 and iteration assumed 1000.

Table 3: Results of FA and GA algorithms and SOP [20] and CBO algorithm

Vulnerability (0-1)	**Annual Water Shortage (MCM)**	**Objective Function**	**Run Time (S)**	**Algorithms and Standard Method**
0.99	564.4	2.50	----	SOP
0.23	301.1	0.23	240	GA
0.2	199.4	0.21	160	FA
0.2	75.8	0.21	44.1	CBO

Also the optimal value of parameters FA and GA algorithms are obtained by sensitivity analysis and in tables, No. 4 and No. 5 have been shown, [20].

Table 4: Optimal parameters of FA algorithm, [20]

γ	**B**	**A**	**Population Size**	**Iteration**
10	**2**	**0.02**	**20**	**1000**

Table 5: Optimal parameters of GA algorithm, [20]

Mutation Function	**Selection Function**	**Mutation Rate**	**Combination Rate**	**Population Size**	**Iteration**
Uniforms	Roulette wheel	0.3	0.8	200	**1000**

Convergence curves of the FA, GA [20] and CBO algorithms, shown in Fig. 3.

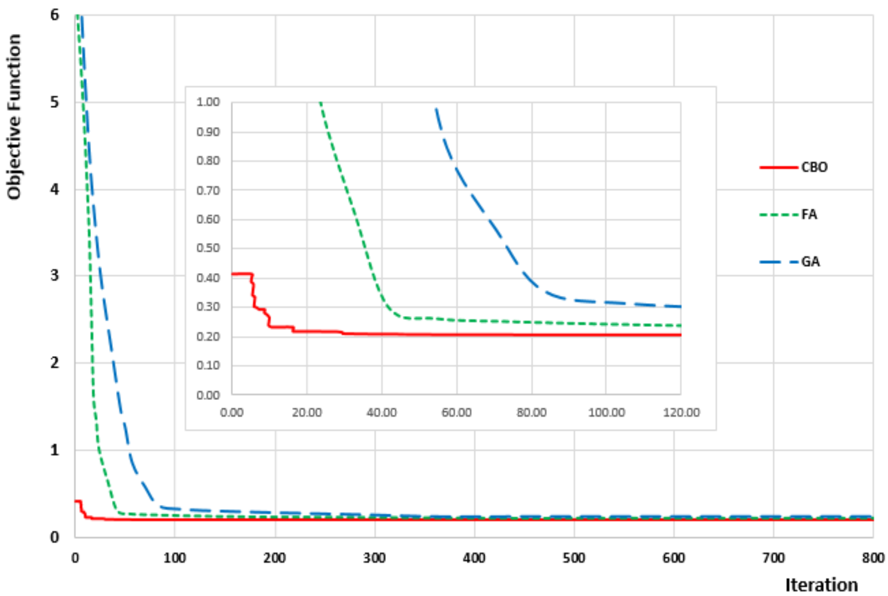

Figure 3. Convergence curves of the FA, GA [20] and CBO algorithms

As shown in Table 3, the results of the CBO algorithm are better than all of the results of FA and GA algorithms and SOP method and only in the objective function and vulnerability is equal to the FA algorithm. Due to the definition of penalty in the objective function, its value remained constant despite the reduction of water shortage, if penalties were not defined, the value of the objective function would be reduced, but reducing the amount of water shortage was not appropriate to reduce vulnerability. One of the most important indicators in optimizing the operation of dam reservoirs is the annual water shortage, the use of the CBO metaheuristic algorithm increases water efficiency and drastically reduces the annual water shortage. The water shortage in the traditional SOP method was about 564 million cubic meters per year, the use of the GA metaheuristic algorithm decreased the water shortage to about 301 million cubic meters per year, and the FA metaheuristic algorithm reduced the annual water shortage to about 199 million cubic meters, [20], and in our paper, applying the CBO metaheuristic algorithm, the annual water shortage reached about 76 million cubic meters. The application of algorithms in the operation of dam reservoirs and the extent of improved operation in this research is quite clear and measurable. The ability of the CBO algorithm to reduce program runtime from 240 seconds in the GA and 160 seconds in the FA to 44 seconds is also very important and interesting.

5. CONCLUSIONS

In this paper, the performance of the CBO metaheuristic algorithm with FA and GA metaheuristic algorithms and the SOP method in optimizing the operation of the Haraz dam reservoir was investigated. According to the calculations, the CBO algorithm has provided better results than the FA and GA algorithms and the SOP method. Among all the effective parameters in the operation of dams, the annual water shortage is very important and vital, so we should try to decrease it by water planning and management. The capability of the CBO algorithm was able to significantly reduce the annual water shortage to about 76 million cubic meters, the water shortage with CBO algorithm is about 123 million cubic meters less than FA algorithm and about 225 million cubic meters less than GA algorithm and about 488 million cubic meters less than SOP method. This is a great success for optimizing the operation of dams reservoirs. In the case of reducing the runtime of the MATLAB program, the time obtained by the CBO algorithm is about 44 seconds which is much better and less than other algorithms. Therefore, the dam operation team must manage the reservoir only with metaheuristic algorithms and select the best algorithm by reviewing and researching continuously, here we reviewed and analyzed the superiority of the CBO algorithm. Saving even one percent of the water reservoirs in any country can lead that country to the prosperity of various sectors such as agriculture and industry. Reducing water shortages means economic development and sustainable local and national development. Unfortunately, despite the valid and accurate answers of metaheuristic algorithms, some dam operators still use traditional methods, therefore, water affairs managers and decision-makers should develop the applying of metaheuristic algorithms such as CBO algorithm by training operation teams. Universities and scientific centers should cooperate with dam reservoir operation teams and help them to establish and run CBO algorithm for optimizing the operation and accurate distribution of water. It is suggested that other researchers improve the results of this paper by using other modified metaheuristic CBO algorithms, such as ECBO and NEBCO, and compare the capabilities and results.

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