Application of artificial bee colony (ABC) algorithm in search of optimal release of Aswan High Dam

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Abstract. The paper presents a study on developing an optimum reservoir release policy by using ABC algorithm. The decision maker of a reservoir system always needs a guideline to operate the reservoir in an optimal way. Release curves have developed for high, medium and low inflow category that can answer how much water need to be release for a month by observing the reservoir level (storage condition). The Aswan high dam of Egypt has considered as the case study. 18 years of historical inflow data has used for simulation purpose and the general system performance measuring indices has measured. The application procedure and problem formulation of ABC is very simple and can be used in optimizing reservoir system. After using the actual historical inflow, the release policy succeeded in meeting demand for about 98% of total time period.

1. Introduction
A guideline is essential for a reservoir system to operate it to get the maximum benefits. Here the ‘benefits’ terms may be defined as fulfilling different wants such as – irrigation, hydropower generation, water supply for domestic and industrial uses etc. Many researches proposed different methodology with different mathematical formulation regarding reservoir optimization model. Evolutionary methods and swarm intelligences becomes very much popular these days in this research field. The most popular and vastly used optimization tool in reservoir system operation modelling is genetic algorithm (GA). Both real valued and binary coded GA has been successfully applied in search of reservoir release policy ([1], [2], [3] and [4]). Selection, cross-over and mutation are the basic operator of a GA procedure. Particle swarm optimization (PSO) got popularity as it free from the complexities of using those operators of GA. According to the study of Kumar & Reddy [5], a modified version of PSO (elitist-mutated PSO) performed better than GA and standard PSO in reservoir release policy.

The application of artificial intelligences getting extensive day by day in every section (like rainfall forecasting engineering [6-7], Global positioning system [8], nonlinear blind signal separation [9], designing spread footing [10] etc.) including reservoir release optimization. In this study we proposed artificial bee colony (ABC) algorithm to optimize the reservoir release policy. ABC is a population based swarm intelligence that mimics the foraging behaviour of natural honey bees. Karaboga [11] firstly proposed the ABC algorithm in optimizing numerical functions and after that several studies proves that ABC shows better performances than GA and PSO algorithm ([12], [13], and [14]). Here we developed an optimum release curve for each month that can provide the amount of water to be release for a known storage condition. Three different inflow categories (high, medium and low) have considered in search of more accurate release volume. Total 36 curves (12 months x 3 inflow category)
have generated in this purposes using ABC optimization algorithm. Each curve shows the amount of release for a definite time period. To verify the model, we used the periodical reliability approach [15], where the number of satisfied period is counted to measure the system performances. Vulnerability and resiliency of the simulation model also measured in this aspect.

2. Artificial bee colony (ABC)

2.1 Foraging principles of natural honey bees

Tereshko [16] identified two major components regarding the process of collecting nectar of honey bees as – ‘recruitment’ and ‘abandonment’. Recruitment refers the involvement of the bees in the process and abandonment refers leaving a food source after using it. The honey bees are identical in shape and size but we can categorize these bees in terms of their working pattern or responsibility during the process they carry. The bees those are currently exploiting a food source may called as ‘employer bees’. The employer bees also carry the information about the sources and after returning to the hive they share the information with other bees waiting in the hive. The bees those are waiting for the information of employer is known as ‘onlooker bees’. To share the information an employer uses a unique technique known as ‘waggle dance’. The waggle dance is a physical movement of the bees and is essential for the foragers as it exhibit some important information about the food sources like – direction, distance and quality/quantity of nectar. After a certain collecting period some food sources becomes useless and here comes the abandonment process. The bees those leave the hive to discover new food sources called as ‘scout bees’.

Figure 1 would help here to understand the basic of foraging process. In figure – 1 let consider an employer bee currently exploiting a food source. After his returning to the hive through E he might have three options to choose. Path E1 that lead him to keep continue to collecting, path E2 if he decided to share the information by dancing and E3 if abandonment of the food source has done. On the other hand an onlooker waits in the hive and observes (position – O) the waggle dance to get recruited. The path S denotes the random search of undiscovered food source and explored by scout bees.

Figure 1. Foraging behaviour of honey bees

2.2 ABC algorithm in reservoir release policy

The basic ABC algorithm can be divided into three phase – Employed bee phase, Onlooker bee phase and Scout bee phase. At first the food sources need to be selected. A set of possible solution of a problem can be taken as the food sources. So if we have a D dimensional problem (where \( i=1,2,...,D \)) then the decision variables \( (x_i) \) act as the members of a single food sources. The value of these decision variables are randomly generated within the variable bounds if they have any. For a typical
monthly water supply problem of a reservoir, a set of release options (consisting 12 values for each month) can be taken as food sources. That means a single source contain 12 consecutive monthly release options. The employed bee tested the fitness values of pre-defined no. of food sources and records the information about them. The quality of each source is the fitness value of the objective function considered to minimize or maximize according to service criteria of the reservoir. Employed bees select a food source and randomly choose a candidate solution within the source to update it providing new values by using equation 1.

\[ v_{ij} = x_{ij} + \phi_{ij} (x_{ij} - x_{ik}) \]  

(1)

Here, \( x_{ij} \) represents the current candidate solution of a source and \( x_{ik} \) represent other randomly chosen solution but must be taken from different neighbour source. \( \phi_{ij} \) is taken as a random number between [-1 to 1]. In case of any violation of variable limits (after using equation 1), the updated food sources are needed to crop to it allowable ranges. The qualities (fitness values) of the new food sources are checked again with the previously stored optimum solution and the decision for survival of a particular source solely depends on the fitness of the solutions.

The onlookers begin to work with the information provided by the employed bees about the food sources. Onlookers select the sources according to their probability of being selected. The probability of each source depends on their fitness value and for total \( N \) no. of sources it can be expressed as equation 2.

\[ P_i = \frac{f(x_i)}{\sum_{n=1}^{N} f(x_n)} \]  

(2)

In equation 2, the probability \( (P_i) \) of any \( i^{th} \) source is the ratio of its individual fitness to the sum of the fitness of all sources. After selection, onlookers use equation 1 to maintain the diversion of the sources. The scout bees create new sources randomly to replace the abandoned food sources (the source posing weak fitness value).

3. Case study: Aswan High Dam (AHD)

Aswan high dam is located across the river Nile in Aswan, Egypt. The AHD is the most important achievement for the people of Egypt as it serves them by providing hydropower, irrigation water, annual flood control and water supply for domestic/industrial uses. The river Nile annually supplies an average of 84x10^9 m^3 of water to the reservoir. All important data used in this study (like – inflow, monthly demand, evaporation and other losses) are adopted from the study of El-Shafie and El-Manadely [17]. The operational zone and water level/storage relations of AHD are given in figure 2. The relationship of storage-(S)/elevation-(H) and storage-(S)/surface area-(A) are given as equation 3 and 4 [17].

\[ H = 79.97 + 0.0369S + 18.87 \ln(S) \]  

(3)

\[ A = -3164.28 + 25.49S + 1092.92 \ln(S) \]  

(4)

In this study equation 4 has used to calculate evaporation volume from monthly evaporation rate. Also the seepage (approx. 0.08 BCM/month) and rock absorption losses (approx. 0.125 BCM/month) has used to calculate total water loss. The inflow pattern and targeted demand has shown in table 1.
For the safe maintenance of the dam, water level for any time should maintain the range of 147 – 183 m. So in terms of storage, the bound for storage capacity is considered as 32 – 162 BCM. According to the dam authority there is another criteria should be followed in the model that, at the end of the month of July the water level should be below 175 m (approx. 122 BCM). For release bounds, 7.5 BCM is taken as the maximum allowable release in a month.

### Table 1. Monthly inflow and water demand (in BCM) for AHD.

| Months | High | Medium | Low | Demand |
|--------|------|--------|-----|--------|
| Jan    | 4.8  | 3.15   | 1.9 | 3.5    |
| Feb    | 3.7  | 1.95   | 0.8 | 3.8    |
| Mar    | 3.5  | 1.7    | 0.55| 4.4    |
| Apr    | 2.7  | 1.15   | 0.3 | 4.1    |
| May    | 2.5  | 1.35   | 0.65| 5.1    |
| Jun    | 2.8  | 1.65   | 0.9 | 6.3    |
| Jul    | 7.7  | 4.75   | 2.8 | 6.8    |
| Aug    | 27.5 | 20.4   | 15.05| 5.9   |
| Sep    | 31   | 24.05  | 18.55| 4.5   |
| Oct    | 21.2 | 15.6   | 11.3| 3.9    |
| Nov    | 10.9 | 7.3    | 4.75| 3.8    |
| Dec    | 6.5  | 4.3    | 2.7 | 3.7    |

### 4. Model formulation

Using the storage bounds, ten discrete values have taken as initial storage. So the model runs each time with different initial storage and inflow conditions. Minimizing the water deficit has considered as the objective function of the study and given in equation 5.

\[
\min f(x) = \sum_{i=1}^{12} (D_i - x_i)^2
\]  

(5)
Here $D_t$ is the targeted demand and $x_t$ is the release for a time period $t$. For calculating the final storage for a month or initial storage for a consecutive month water mass balance relation has used (equation 6).

$$S_{t+1} = S_t + \text{Inflow}_t - \text{Release}_t - \text{Losses}_t$$

Penalty function method used to handle the reservoir bounds and other constraints. The penalty terms for release and storage bounds are given as follows-

$$\text{penalty}_1 = \begin{cases} 0 & \text{if } S_t > S_{\text{min}} \\ \frac{C_1(S_{\text{min}} - S_t)^2}{S_t < S_{\text{min}}} & \text{if } S_t < S_{\text{min}} \end{cases}$$

$$\text{penalty}_2 = \begin{cases} 0 & \text{if } S_t < S_{\text{max}} \\ \frac{C_2(S_t - S_{\text{max}})^2}{S_t > S_{\text{max}}} & \text{if } S_t > S_{\text{max}} \end{cases}$$

$$\text{penalty}_{AHD} = \begin{cases} 0 & \text{if } S_{\text{Set}} < 122 \text{ BCM} \\ \frac{C(S_{\text{Set}} - 122)^2}{S_{\text{Set}} > 122 \text{ BCM}} & \text{if } S_{\text{Set}} > 122 \text{ BCM} \end{cases}$$

5. Results and discussion

Total 36 release curve has developed for every month of a year with three different inflow categories. Such curve for the month of January has given in figure 3. From the figure we can see that a release in high inflow period can meet the demand even in low storage capacity but as the storage is getting higher value, oversupply is required to keep the storage in safe range.

![Figure 3. Release options for the month of January with different inflow conditions.](image)

The fitness value through all iteration has given in figure 4. According to the figure 4, ABC optimization reached to the optimal solution very fast. For verification of the model, 18 years (from Aug 1980 to Jul 1998) of historical inflow data has used as an input of the release curves. The simulation results for ABC release has given in figure 5. In figure 5 we can see that how the release options given by ABC model minimize the deficit and close to demand for every month. From the simulation results, performance measuring indices has measured [18]. These indices can be given as – reliability (number of time period able to meet the demand over total time period), resiliency (maximum consecutive shortage period) and vulnerability (worst shortage ever) has calculated and given in table 2.
Figure 4. Objective function values through 1000 iterations

Figure 5. Simulation results of ABC release policy using historical inflow

Table 2. System performance indices

| Performance measuring indices | ABC release policy |
|-------------------------------|-------------------|
| Reliability                   | 98.14 %           |
| Resiliency (months)           | 1                 |
| Vulnerability (% of demand)   | 1.11              |

In table 2 we can see that the release policy developed from ABC model satisfied the demand more than 98% of the total historical time period. Also the ability of getting back from a shortage period is very good as the resiliency is 1. Only 1.11% of demand is the worst shortage scenario that the model has experienced.

6. Conclusion
ABC is very fast and the results are very much reliable in finding optimal solutions, as we can see in figure 4 and 5. The simplicity of the ABC optimization technique is the main attraction over GA and PSO algorithm in finding release policy of a reservoir. Less parameter handling, simple analyzing of
the problem and also very important - the practical application in a reservoir system suggest to consider ABC algorithm in this research field.

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