

Optimal Reservoir Operation Using Genetic Algorithm: A Case Study of Ukai Reservoir Project

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ABSTRACT: Application of optimization techniques for determining the optimal operating policy of reservoirs is a major issue in water resources planning and management. Genetic Algorithm is an optimization technique, based on the principle of natural selection, derived from the theory of evolution, are popular for solving optimization problems. The main aim of the present study is to develop a policy for optimizing the release of water for the purpose of irrigation. The fitness function used is minimizing the squared deviation of monthly irrigation demand along with the squared deviation in mass balance equation. The months considered are from July to October for three years from year 2007 to 2009. The decision variables are monthly releases for irrigation from the reservoir and initial storages in reservoir at beginning of the month. The constraints considered for this optimization are the bounds for the releases and reservoir capacity. Results show that in the year 2007, for months of July and August, 625 and 1573.86 MCM of water is saved respectively. In the year 2008, for July 65.67 MCM, August 27.15 MCM, September 35.32 MCM and October 62.91 MCM of water is saved. In the year 2009, for July 49.18 MCM, August 35.48 MCM, and in October 43.51 MCM of water is saved. Hence, GA model, if applied to the Ukai reservoir project in Gujarat State, India, can completely satisfy downstream irrigation demands and releases are minimized which leads to considerable amount of saving in water.

KEYWORDS: Genetic algorithm, Optimization, Ukai reservoir project.

I. INTRODUCTION

Genetic Algorithms (GAs) are search procedures based on the natural genetics and natural selection. They combine the concept of the survival of fittest with genetic operators extracted from nature to form a robust search mechanism. Goldberg [1] identified the following differences between GAs and the traditional optimization methods:

- GAs work with coding of the parameter set but not with the parameters themselves.
- GAs search from a population of points, not a single point.
- GAs use objective function information, not derivatives or other auxiliary knowledge.
- GAs use probabilistic transitions rules, not deterministic rules.

Use of Genetic Algorithm (GA) in determining the optimal reservoir operation policies, is receiving significant attention from water resources engineers. A large number of works has been reported on the application of GA for various complex reservoir problems. East and Hall [2] has applied GA to a reservoir problem with the objective of maximizing the power generation and irrigation. Wardlaw and Sharif [3] evaluated several formulations of a genetic algorithm for four-reservoir, deterministic, finite-horizon problem. They also considered a nonlinear four-reservoir problem, one with extended time horizons and a complex ten-reservoir problem. They concluded that genetic algorithm approach is more robust. Sharif and Wardlaw [4] presented genetic algorithm approach for optimization of multi-reservoir systems for a case study in Indonesia and its results were compared with those of discrete differential dynamic

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programming. They concluded that genetic algorithm results are closer to the optimum. Kuo et al. [5] used genetic algorithm based model for irrigation project planning for a case study of Delta, Utah, for maximization of economic benefits for a command area. They compared solution of genetic algorithms with that of Simulated Annealing and iterative improvement techniques. Ahmed and Sarma [6] developed a GA model for deriving the optimal operating policy and compared its performance with that of stochastic dynamic programming (SDP) for a multipurpose reservoir. The objective function of both GA and SDP was to minimize the squared deviation of irrigation release. Sensitivity analysis was carried out for mutation and cross over. They found that GA model releases nearer to the required demand and concluded that GA is advantageous over SDP in deriving the optimal operating policies. Janga Reddy and Nagesh Kumar [7] developed Multi-objective Evolutionary Algorithm to derive a set of optimal operation policies for a multipurpose reservoir system and concluded that the results obtained using the proposed evolutionary algorithm was able to offer many better alternative policies for the reservoir operation, giving flexibility to choose the best out of them. Jotiprakash and Ganesan Shanthi [8] developed a GA model for deriving the optimal operating policy for a multi-purpose reservoir. The objective function was to minimize the squared deviation of monthly irrigation demand deficit along with the deviation in the target storage. Sensitivity analysis was carried out for crosses over and size of population, and they found that GA model releases nearer to the required demand and concluded that GA model is advantageous in deriving optimal operating policies. Mathur and Nikam [9] optimized the operation of an existing multipurpose reservoir in India using GA, and derived reservoir operating rules for optimal reservoir operations. Tripathy and Pradhan [10] developed a GA model for deriving optimal operating policy for Hirakud reservoir in India. The results obtained by GA model are compared with the current policy used by the Government of Odisha at that time and observed that GA gives a better policy. Srinivasa and Kumar [11] used the GA method to design the irrigation systems for a suitable cultivation pattern in India.

In the present study, a GA model has been used for optimum reservoir operation. The objective of this study is to minimize the squared deviation of monthly irrigation demand deficit along with squared deviation of mass balance equation. The decision variables used are the release for irrigation demand from the reservoir and initial storage in each month. The constraints used for this optimization are bounds for the releases and reservoir capacity.

II. STUDY AREA

The area selected for the present study is the catchment area of the Ukai dam, which is located across Tapi River near Ukai village of Fort Songadh taluka in Surat district. Its catchment is located between longitudes 73°32'25" to 78°36'3" E and latitudes 20°5'0" to 22°52'30" N. The dam is located at about 29 km upstream of the Kakrapar weir. The total catchment area of the Ukai reservoir is 62,225 sq. km, which lies in the Deccan plateau. The catchment of the dam covers large areas of 12 districts of Maharashtra, Madhya Pradesh and Gujarat. The districts that lie in the catchment include Betul, Hoshangabad, Khandwa, and Khargaoon of Madhya Pradesh; Akola, Amravati Buldhana, Dhule, Jalgaon and Nasik of Maharashtra and Bharuch and Surat of Gujarat state. The command area of 66,168 Ha is spread over the districts of Surat, Tapi, Navsari and Valsad.

III. MODEL DEVELOPMENT

In the present study, the fitness function of the GA model is minimizing the squared deviation of monthly irrigation demand and squared deviation in mass balance equation. The objective function is given by equation 1.

$$\sum_{t=1}^{12} (R_t - D_t)^2 + \sum_{t=1}^{12} (S_t - S_{t+1} + I_t - R_t - E_t)^2 \quad (1)$$

Where,

- R_t = Monthly irrigation release for the month 't'.
- D_t = Monthly downstream irrigation demand for the month 't'.
- S_t = Initial storage in the beginning of month 't'.
- S_{t+1} = Final storage at the end of month 't'.
- I_t = Monthly inflow during the period 't', and

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E_t = Monthly evaporation loss from the reservoir during the month 't'.

The above fitness function of GA model is subjected to the following constraints and bounds,

A. Release constraint.

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

$$R_t \geq D_t, t = 1, 2, 3, 4 \quad \text{----- (2)}$$

B. Storage constraint.

The reservoir storage in any month should not be more than the capacity of the reservoir, and should not be less than the dead storage. Mathematically this constraint expressed as:

$$S_{min} \leq S_t$$

and

$$S_t \leq S_{max}, t = 1, 2, 3, 4 \quad \text{----- (3)}$$

Where,

S_{min} = Dead Storage of the reservoir in MCM and

S_{max} = Maximum capacity of the reservoir in MCM.

IV. RESULTS AND DISCUSSION

To apply Genetic algorithm (GA) to the above formulated model, the data used are inflow, demand, actual release, evaporation and storage in MCM. The important input variables in present GA model study are the monthly inflow in to the reservoir system and monthly irrigation demands for the month of July, August, September and October from year 2007 to 2009. The main objective of the study is to compute the quantity of water that should be released to meet the monthly irrigation demand. Since, the fitness function is based on the monthly irrigation demands (D_t) and monthly inflow in the reservoir (I_t), so reservoir releases for irrigation (R_t), and initial storage (S_t) in the reservoir in monthly time step are chosen as decision variable. Thus eight decision variables are considered for a year. The parameters considered in GA Population size from 5 to 20, probability of crossover of 0.80, number of generations from 5 to 50 and selection function Roulette wheel selection. After applying GA to the above formulated model the following results are generated which gives the releases by GA and that we consider as optimum releases for year 2007 to 2009.

TABLE 1: DEMAND, ACTUAL RELEASE AND OBTAINED RELEASE BY GA FOR THE YEAR 2007

Month	July	August	September	October
Actual Release, MCM	3135.12	2912.65	1696.92	499.46
Release by GA, MCM	2509.87	1338.79	1720.96	505.81
Demand, MCM	2508.09	1336.84	1720.84	505.79

Table 1 shows the values of the actual release, release obtained by applying genetic algorithm and the demand for each of the month of July, August, September and October for the year 2007. From the values of the Releases by GA, it can be shown that for each of the month of July, August, September and October, the demands are completely satisfied. Table 1 is represented graphically in Fig. 1.

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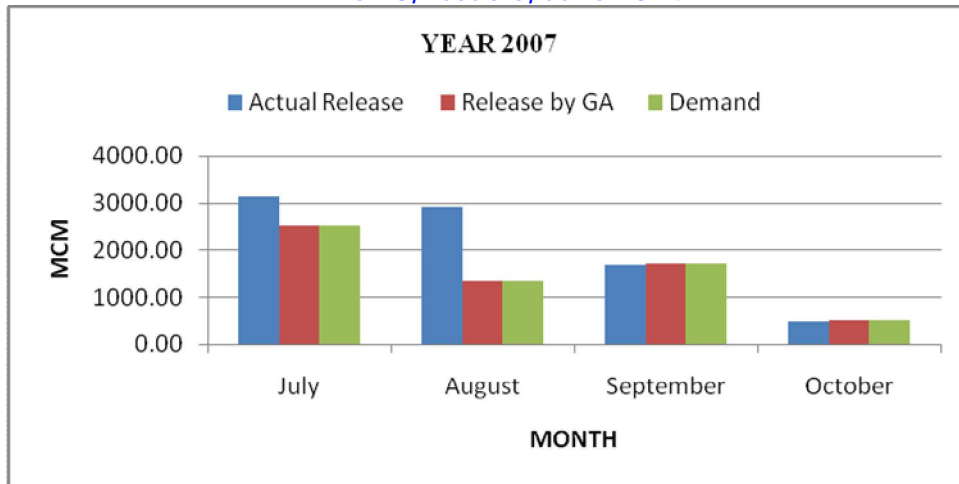


Fig.1 Actual Release, Release by GA and Demand for year 2007

Fig.1 shows the Actual release, release obtained by applying genetic algorithm and demand for the months of July, August, September and October respectively for the year 2007. From Fig.1, it is observed that in the month of July and August the releases obtained by GA is less than the actual release and in the month of September and October the release obtained by GA is more than the actual release resp. but care is taken to satisfy the demands. So, these obtained releases for the month of July, August, September and October are the optimal releases. The amount and percentage of water that can be saved is shown in Table 2.

TABLE 2: AMOUNT OF WATER SAVED IN MCM AND IN PERCENTAGE FOR THE YEAR 2007

Month	July	August	September	October
Amount of Water Saved, MCM	625.25	1573.86	*	*
Percentage of Water Saved, %	19.94	54.04	*	*

Table 2 shows the amount of water saved in MCM and in percentage for each of the months of July, August, September and October respectively for the year 2007. In the month of July and August 625.25 and 1573.86 MCM of water is saved respectively, which shows that 20 % of water is saved from the actual release in July and similarly almost 54 % in August. The asterisk (*) is used to show that the release obtained by GA is more than the actual release, so water is not saved, but instead care is taken to fulfil the demands.

TABLE 3: DEMAND, ACTUAL RELEASE AND OBTAINED RELEASE BY GA FOR THE YEAR 2008

Month	July	August	September	October
Actual Release, MCM	330.42	137.90	188.60	324.48
Release by GA, MCM	264.75	110.75	153.28	261.57
Demand, MCM	264.43	110.32	150.88	259.58

Table 3 shows the values of the actual release, release obtained by applying genetic algorithm and the demand for each of the month of July, August, September and October for the year 2008. From the values of the Releases by GA, it can be shown that for each of the month of July, August, September and October, the demands are completely satisfied. Table 3 is represented graphically in Fig. 2.

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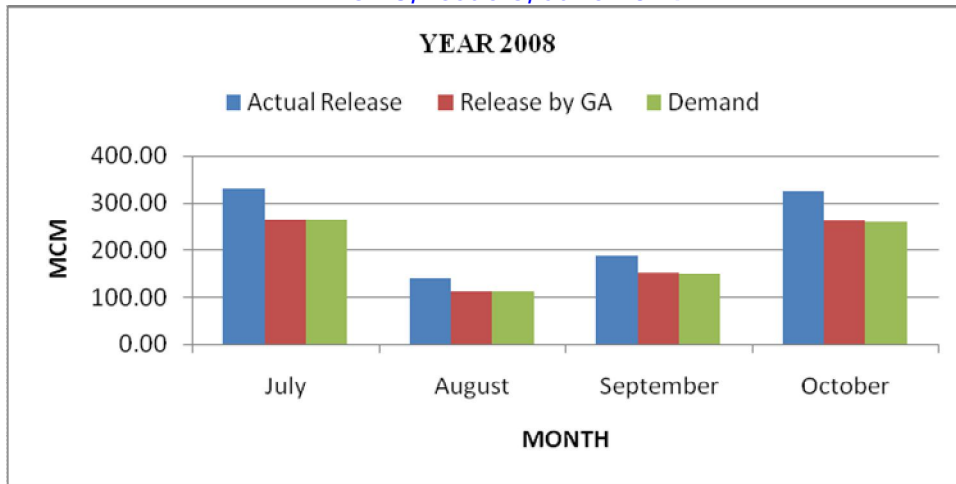


Fig.2 Actual Release, Release by GA and Demand for year 2008

Fig.2 shows the Actual release, release obtained by applying genetic algorithm and demand for the month of July, August, September and October respectively for the year 2008. From Fig.2, it is observed that in each of the month of July and August, September and October the releases obtained by GA are less than the actual release. So, these obtained releases for the month of July, August, September and October are the optimal releases. The amount and percentage of water that can be saved is shown in Table 4.

TABLE 4: AMOUNT OF WATER SAVED IN MCM AND IN PERCENTAGE FOR THE YEAR 2008

Month	July	August	September	October
Amount of Water Saved, MCM	65.67	27.15	35.32	62.91
Percentage of Water Saved, %	19.87	19.69	18.73	19.39

Table 4 shows the amount of water saved in MCM and in percentage for each of the months of July, August, September and October respectively for the year 2008. In the month of July, August, September and October, 65.67, 27.15, 35.32 and 62.91 MCM of water is saved respectively, which is almost nearby 20 % of saving in water from the respective actual release in each respective month.

TABLE 5: DEMAND, ACTUAL RELEASE AND OBTAINED RELEASE BY GA FOR THE YEAR 2009

Month	July	August	September	October
Actual Release, MCM	175.00	180.10	233.25	224.95
Release by GA, MCM	125.82	144.62	233.91	181.44
Demand, MCM	125.68	144.08	233.25	179.97

Table 5 shows the values of the actual release, release obtained by applying genetic algorithm and the demand for each of the month of July, August, September and October for the year 2007. From the values of the Releases by GA, it can be shown that for each of the month of July, August, September and October, the demands are completely satisfied. Table 5 is represented graphically in Fig. 3.

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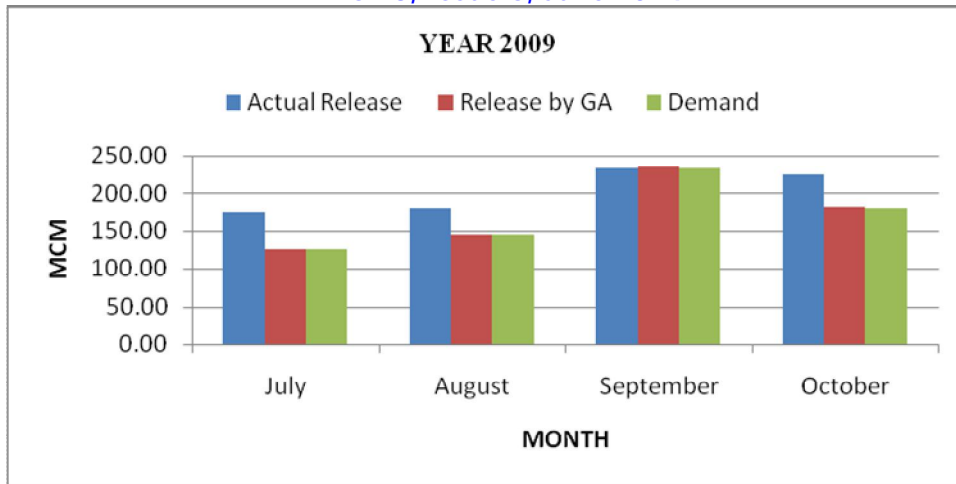


Fig.3 Actual Release, Release by GA and Demand for year 2009

Fig.3 shows the Actual release, release obtained by applying genetic algorithm and demand for the month of July, August, September and October respectively for the year 2009. From Fig.3, it is observed that in the month of July, August and October the releases obtained by GA is less than the actual release and in the month of September the release obtained by GA is more than the actual release, but care is taken to satisfy the demands. So, these obtained releases for the month of July, August, September and October are the optimal releases. The amount and percentage of water that can be saved is shown in Table 6.

TABLE 6: AMOUNT OF WATER SAVED IN MCM AND IN PERCENTAGE FOR THE YEAR 2009

Month	July	August	September	October
Amount of Water Saved, MCM	49.18	35.48	*	43.51
Percentage of Water Saved, %	28.10	19.70	*	19.34

Table 6 shows the amount of water saved in MCM and in percentage for each of the monthS of July, August, September and October respectively for the year 2007. In the month of July, August and October, 49.18, 35.48 and 43.51 MCM of water is saved respectively in each month, which shows that almost 28 % of water is saved from the actual release in July and similarly almost around 20 % in August and October respectively. The asterisk (*) is used to show that the release obtained by GA is more than the actual release in the month of September, so water is not saved, but instead care is taken to fulfil the demands.

V. CONCLUSIONS

An optimal policy has been developed for release of water from the Ukai reservoir project for the purpose of irrigation. The releases developed by Genetic algorithm satisfy completely the irrigation demands for all the four months i.e. July, August, September and October for each year from year 2007 to 2009 respectively. The amount of water saved in the months of July and August for year 2007 is 625.25 MCM and 1573.86 MCM respectively, similarly in the months of July, August, September and October for year 2008, it comes out to 65.67 MCM, 27.15 MCM, 35.32 MCM and 62.91 MCM respectively and in July, August and October for year 2009, it is 49.18 MCM, 35.48 MCM and 43.51 MCM respectively. Thus, almost in nine out of twelve months the optimal releases obtained by genetic algorithm, are less than the actual releases, which leads to considerable amount in saving of water.

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