Optimal crop water allocation coupled with reservoir operation by Genetic Algorithm and Non-Linear Programming (GA-NLP) hybrid approach

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Abstract. This paper presents a Genetic Algorithm and Non-Linear Programming (GA- NLP) hybrid model to derive steady state optimal reservoir operating policies for a reservoir. In the present study, the objective is maximizing the yields of all the crops in the command area considering yield response to water deficit subject to constraints on reservoir water balance, storage bounds, channel capacities and minimum water requirements. Decision variables of the model are fortnight water allocations to each crop grown under left & right main canals and d/s releases. The model developed is applied to the Nagarjunasagar reservoir in Andhra Pradesh, India. Various levels of dependable inflows entering into the reservoir (75%, 80% & 85%) are considered in the present study. Optimal policy obtained by proposed model are validated through simulation and compared with Standard operating policy (SOP). The results obtained using the proposed model gives guidelines to reservoir managers to take decisions. Results reveal that GA-NLP model can be effectively used for optimal allocation of limited available water resources to any reservoir.

1. Introduction

India is a basically agricultural country. The major employment and economy depends on agricultural sector. For getting maximum crop yield timely supply of required quantity water is very essential and farmers will be benefited. When adequate water is available, there is no problem of allocating water satisfying crop water requirements in different intraseasonal periods. But when the water availability is less than the required amount, there will be competition among the crops for allocation. This necessitates the distribution of deficits optimally among intraseasonal periods of competing crops taking consideration of yield response to water deficit. The reservoir operation problem is a high dimensional, dynamic, non-linear and non-convex optimization problem [1-3] subject to many constraints such as reservoir water balance, storage bounds, channel capacities, outflow rates and installed power generation capacities.

Determination of optimal allocation of water in agricultural lands and optimal reservoir operation policies by different techniques has been the subject of extensive research in the past decades by various researchers. Linear programming has been used by many researchers for finding optimal cropping pattern and reservoir operation [4,5]. When the objective function and constraints are non-linear in nature, non-linear optimization techniques like Non-Linear Programming (NLP) and Dynamic programming (DP) are adopted [6,7]. When inflows into the reservoir are considered to be uncertain, reservoir operating policies are obtained by stochastic dynamic programming (SDP) and fuzzy logic [8-12]. Curse of dimensionality restricts use of DP in case of large complex problems.

Starting from an initial set of random population unlike conventional techniques, there are more chances to cover the entire search space in attaining the global optimum. It is the main advantage of evolutionary algorithms like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), simulated annealing (SA), etc. These are most effective and best alternatives for solving non-linear, non-convex
problems like optimal irrigation scheduling and reservoir operating policies. In recent years these evolutionary algorithms for deriving optimal reservoir operating policies are being used to overcome the difficulties in the conventional techniques.

GA model is developed for optimal operation of reservoir [13]. The performance of their proposed model is compared with DP and concluded that performance of GA is better than DP. GA model is applied to non-linear multi-reservoir problem [14] and concluded that GA is robust and it can be used as alternative to SDP approaches. The state-of-the-art in optimization of reservoir system management and operations by evolutionary algorithms using GA is discussed in [15]. GA model is applied for obtaining an optimal crop water allocations and optimal operating policy of a reservoir [16]. Their objective is to maximize the yield in a multi-crop environment and concluded that the policy derived by GA is similar to that obtained by LP. A GA model is developed and applied to Pechiparai reservoir in Tamil Nadu, India [17] to derive the optimal operational strategies. Reservoir operating policies are developed for reservoir inflows of various probabilities by using GA [18]. The capability of GA is explored by solving irrigation scheduling problem [19] and concluded that GA performs well by comparing the solution with Integer programming (IP). Multi-reservoir problem is solved by GA maximizing the benefits from power generation and irrigation [20]. GA model is developed for maximizing energy production of multi-reservoirs on Colorado River [21]. The policy developed by GA model is compared with the existing operating policy by conventional method and concluded that GA is more efficient than the conventional method. Optimal trade-off between the multiple objectives are developed by using multi-objective GA [22, 23]. Improved GA – Simulated Annealing (IGA-SA) model is applied to a multi-reservoir system [24], the hybrid model performs better than GA, SA and DP in terms of computation time. A hybrid GA – SQP (sequential quadratic programming) algorithm is developed for solving analog design problems [25] and concluded that GA-SQP performs better than SQP in terms of reaching convergence and computation time.

In the present study, operating policies of a reservoir maximizing the crop yields are obtained by adopting GA-NLP hybrid model. 75%, 80% & 85% dependable inflows into the reservoir are considered. Optimal policies obtained by proposed models are validated through simulation and compared with SOP.

1.1 Genetic Algorithm

GA search starting from an initial set of random population and generates successive "generations" of solutions. This is the major difference between conventional optimization techniques and GA. Development of GA is motivated by Darwin's theory of evolution - "survival of the fittest". The operations carried out in this method are selection, crossover and mutation. The fittest individuals will be selected and produce new population by performing above operations to improve the solution quality. In selection process, parents are to be selected from the initial population according to their fitness. More chances are there to act as parents for those chromosomes having better fitness. The parents are crossover with some crossover probability to produce offspring (children). If there is no crossover, the children are the exact copy of the parents. Offspring's are mutated at each locus with a small mutation probability. Mutation helps the search algorithm to escape from local minima and it is used to maintain diversity in the population. Replace the initial population with new offspring. Perform the above operations to the new population until the termination criteria is reached. A constrained problem can be solved by GA converting it into unconstrained problem by incorporating a penalty function in the objective function. The detailed procedure of GA is available in [26].
1.2 Non-Linear Programming
Sequential Quadratic Programming (SQP) is the most popular method to solve non-linear nature problems. It requires an initial feasible solution to reach global optimal solution to avoid local optima. This method follows Newton’s method for solving constrained non-linear problems as it is done for un-constrained problems. It is an iterative process, in each iteration an approximation made to the Hessian of the Lagrangian function which uses a quasi-Newton updating method. Karush-Kuhn-Tucker (KKT) equations are the necessary conditions [27, 28] to solve non-linear constrained optimization problems.

1.3 Proposed GA-NLP Hybrid Approach
For finding global optimal solution by GA, a thorough sensitivity analysis is required for choosing the GA parameters and NLP requires initial feasible solution for getting optimal solution for faster convergence. To avoid the difficulty in selecting finer values of GA parameters for obtaining global optimal solution GA-NLP hybrid approach is considered. In GA-NLP hybrid approach the solution obtained from GA is taken as initial solution to NLP for finding the global optimum by using MATLAB software. The flow chart of GA-NLP hybrid approach adopted in the present study is shown in figure 1.

![Flow chart of GA-NLP hybrid approach.](image1)

![Layout of Nagarjunasagar reservoir](image2)
2. Study Area

The study area considered in the present work is Nagarjunasagar reservoir. It was built across the river Krishna in Andhra Pradesh, India. The location of the reservoir is at latitude 16°34' N and longitude 79°19' E. The layout of the reservoir system is shown in figure 2. The gross storage capacity of the reservoir is 11560 Mm³ (MCM) having a live storage of 5730 Mm³. The full reservoir level is 179.83 m. The catchment area of the reservoir is 214,185 km² and the water spread area at full reservoir level is 285 km².

The length and height of the dam are 1.6 km and 150 m respectively. It consists of 26 spill gates with size 13 m x 14 m. The lengths of left & right main canals are 179 km and 203 km respectively having equal carrying capacity of 311.5 m³/s. The Nagarjunasagar left main canal (NSLC) irrigates 0.3869 million hectares (M Ha) of land in Nalgonda, Krishna, West Godavari and Khammam districts. The Nagarjunasagar right main canal (NSRC) irrigates 0.4505 M Ha of land in Guntur and Prakasam districts. A power house is located at the d/s of the river having an installed capacity of 810 MW and releases from the power house stabilize irrigation under Krishna delta system. Various levels of dependable inflows (75%, 80% & 85%) into the reservoir and d/s releases are obtained from the available data of past 43 years. The meteorological data required for calculation of crop water requirements under right and left main canal command areas is obtained from IMD stations Rentachintala & Khammam respectively and is shown in table 1. Data of crops considered are shown in table 2. Fortnight wise inflows, minimum d/s releases and crop demands under each canal are shown in table 3.

| Month | Khammam ETo | Rainfall | Rentachintala ETo | Rainfall | Reservoir evaporation |
|-------|-----------|---------|------------------|---------|----------------------|
| Jan   | 116.7     | 1.6     | 120              | 0.4     | 90                   |
| Feb   | 154.2     | 7.3     | 141.6            | 9.3     | 90                   |
| Mar   | 195.3     | 10.5    | 168.6            | 6.1     | 174                  |
| Apr   | 208.0     | 25.5    | 184.8            | 9.6     | 228                  |
| May   | 224.1     | 27.1    | 193.2            | 40.8    | 240                  |
| Jun   | 180.9     | 126.5   | 170.1            | 86.2    | 180                  |
| Jul   | 120.4     | 260.1   | 147.6            | 115.3   | 144                  |
| Aug   | 116.4     | 185.5   | 139.2            | 114.6   | 144                  |
| Sep   | 115.8     | 164.5   | 130.2            | 146.1   | 144                  |
| Oct   | 110.9     | 107.1   | 123.3            | 123.8   | 126                  |
| Nov   | 106.4     | 33.8    | 114.3            | 41.1    | 99                   |
| Dec   | 115.3     | 3.9     | 111              | 13.3    | 99                   |
Table 2. Crop Data under Nagarjunasagar Command Area.

| Crops (Season) | Crop Coefficients Kc | Area (ha) |
|----------------|----------------------|-----------|
|                | Initial | Mid   | End    |           |
| NSRC           |         |       |        |           |
| Rice1 (K)      | 16-Jul  | 1.05  | 1.175  | 0.902    | 50000    |
| Rice2 (K)      | 1-Aug   | 1.05  | 1.175  | 0.902    | 50000    |
| Groundnut (K)  | 1-Jul   | 0.831 | 1.137  | 0.562    | 40000    |
| Sorghum (K)    | 16-Jul  | 0.835 | 0.958  | 0.489    | 70000    |
| Grams (K)      | 16-Jul  | 0.835 | 1.016  | 0.559    | 100000   |
| Cotton         | 16-Jul  | 0.814 | 1.105  | 0.702    | 100000   |
| Chilli         | 16-Aug  | 0.863 | 0.967  | 0.708    | 40000    |
| Groundnut (R)  | 1-Nov   | 0.761 | 1.152  | 0.623    | 40000    |
| Sorghum (R)    | 1-Nov   | 0.761 | 1.002  | 0.582    | 30000    |
| Grams (R)      | 1-Nov   | 0.761 | 1.056  | 0.625    | 80000    |
| NSLC           |         |       |        |           |
| Rice1 (K)      | 16-Jul  | 1.05  | 1.175  | 0.902    | 100000   |
| Rice2 (K)      | 1-Aug   | 1.05  | 1.175  | 0.902    | 100000   |
| Cotton         | 16-Jul  | 1.01  | 1.085  | 0.69     | 10000    |
| Chilli         | 16-Aug  | 0.971 | 0.96   | 0.697    | 10000    |
| Groundnut (R)  | 16-Oct  | 0.884 | 1.133  | 0.608    | 40000    |
| Sorghum (R)    | 16-Oct  | 0.884 | 0.975  | 0.551    | 80000    |
| Grams (R)      | 16-Oct  | 0.884 | 1.038  | 0.601    | 80000    |

| Crop (Season) | growth period in fortnights and | Kc values |
|---------------|---------------------------------|-----------|
|               | Initial | Crop Development | Flowering | Grain formation | Ripening |
| NSRC          |         |                   |           |                |          |
| Rice1 (K)     | 1, 1.07 | 2, 1.07           | 1, 2.15   | 2, 2.15        | 1, 0.33  |
| Rice2 (K)     | 1, 1.07 | 2, 1.07           | 1, 2.15   | 2, 2.15        | 1, 0.33  |
| Groundnut (K) | 2, 0.20 | 1, 0.20           | 1, 0.80   | 2, 0.60        | 2, 0.20  |
| Sorghum (K)   | 1, 0.20 | 2, 0.20           | 1, 0.55   | 2, 0.45        | 1, 0.20  |
| Grams (K)     | 1, 0.05 | 2, 0.05           | 1, 0.40   | 2, 0.35        | 1, 0.20  |
| Cotton        | 2, 0.20 | 2, 0.20           | 3, 0.50   | 3, 0.50        | 3, 0.25  |
| Chilli        | 2, 0.40 | 3, 0.40           | 2, 0.80   | 2, 0.80        | 1, 0.40  |
| Groundnut (R) | 2, 0.20 | 1, 0.20           | 1, 0.80   | 2, 0.60        | 2, 0.20  |
| Sorghum (R)   | 1, 0.20 | 2, 0.20           | 1, 0.55   | 2, 0.45        | 1, 0.20  |
| Grams (R)     | 1, 0.05 | 2, 0.05           | 1, 0.40   | 2, 0.35        | 1, 0.20  |
| NSLC          |         |                   |           |                |          |
| Rice1 (K)     | 1, 1.07 | 2, 1.07           | 1, 2.15   | 2, 2.15        | 1, 0.33  |
| Rice2 (K)     | 1, 1.07 | 2, 1.07           | 1, 2.15   | 2, 2.15        | 1, 0.33  |
| Cotton        | 2, 0.20 | 2, 0.20           | 3, 0.50   | 3, 0.50        | 3, 0.25  |
| Chilli        | 2, 0.40 | 3, 0.40           | 2, 0.80   | 2, 0.80        | 1, 0.40  |
| Groundnut (R) | 2, 0.20 | 1, 0.20           | 1, 0.80   | 2, 0.60        | 2, 0.20  |
| Sorghum (R)   | 1, 0.20 | 2, 0.20           | 1, 0.55   | 2, 0.45        | 1, 0.20  |
| Grams (R)     | 1, 0.05 | 2, 0.05           | 1, 0.40   | 2, 0.35        | 1, 0.20  |
**Table 3.** Inflows, Minimum d/s Flow Requirements and NSLC & NSRC Demands.

(in MCM)

| Fort night | Dependable Inflows  | Left canal demand | Right canal demand | D/S demand |
|------------|---------------------|-------------------|--------------------|------------|
|            | 75% PE | 80% PE | 85% PE |                |              |                |              |
| JUL I      | 587.500 | 326.075 | 250.125 | 333.333 | 186.653 | 302.357 |
| JUL II     | 587.500 | 326.075 | 250.125 | 333.333 | 355.761 | 302.357 |
| AUG I      | 1600.760 | 1430.350 | 1250.075 | 3.127 | 216.427 | 320.508 |
| AUG II     | 1600.760 | 1430.350 | 1250.075 | 10.233 | 263.261 | 320.508 |
| SEP I      | 1229.300 | 1182.250 | 860.075 | 47.486 | 161.567 | 341.916 |
| SEP II     | 1229.300 | 1182.250 | 860.075 | 51.742 | 172.496 | 341.916 |
| OCT I      | 1127.520 | 1054.930 | 875.270 | 125.130 | 208.090 | 227.413 |
| OCT II     | 1127.520 | 1054.930 | 875.270 | 152.208 | 152.208 | 227.413 |
| NOV I      | 444.180 | 379.400 | 366.060 | 239.382 | 289.584 | 83.472 |
| NOV II     | 444.180 | 379.400 | 366.060 | 178.030 | 230.465 | 83.472 |
| DEC I      | 307.500 | 226.350 | 182.075 | 218.934 | 277.528 | 4.528 |
| DEC II     | 307.500 | 226.350 | 182.075 | 280.913 | 4.528 |
| JAN I      | 197.300 | 174.335 | 152.775 | 218.258 | 285.510 | 108.684 |
| JAN II     | 197.300 | 174.335 | 152.775 | 170.022 | 238.110 | 108.684 |
| FEB I      | 146.080 | 133.720 | 127.075 | 38.256 | 155.798 | 223.311 |
| FEB II     | 146.080 | 133.720 | 127.075 | 35.770 | 223.311 |
| MAR I      | 108.500 | 100.900 | 91.280 | 91.280 | 304.046 |
| MAR II     | 108.500 | 100.900 | 91.280 | 0.000 | 304.046 |
| APR I      | 87.050 | 79.200 | 76.075 | 0.000 | 4.812 |
| APR II     | 87.050 | 79.200 | 76.075 | 0.000 | 4.812 |
| MAY I      | 44.050 | 37.685 | 22.630 | 0.000 | 0.000 |
| MAY II     | 44.050 | 37.685 | 22.630 | 0.000 | 0.000 |
| JUN I      | 78.420 | 75.435 | 60.075 | 0.000 | 90.430 |
| JUN II     | 78.420 | 75.435 | 60.075 | 0.000 | 90.430 |
3. Model Formulation

Fortnight wise steady state reservoir operating model is formulated considering a planning horizon of a year. The model is formulated to maximize relative yield of various crops under left & right main canal command area. Crop yield reduction is proportional to the water deficit in any growth stage [29] and is related by,

\[
\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{AET}{PET}\right)
\]

Relative yield \(= \frac{Y_a}{Y_m} = 1 - K_y \left(1 - \frac{AET}{PET}\right)\)  

Where \(Y_a\) is the actual yield, \(Y_m\) is maximum yield with full irrigation, \(K_y\) is the yield response factor, \(AET\) is the actual evapotranspiration, \(PET\) is the evapotranspiration requirement of the crop.

The above equation in the present study is considered as

\[
\left(1 - \frac{Y_a}{Y_m}\right) = 1 - K_y \left(1 - \frac{R}{D}\right)
\]

Where \(R\) is the irrigation applied and \(D\) is the crop water demand. Detailed guidelines for calculating crop water requirements are given by food and agricultural organization [30].

A penalty term is added in the objective function to minimize the reservoir spill. The proposed objective function is,

\[
\text{Maximize} \quad F = \sum_{i=1}^{N_i} \sum_{c=1}^{N_c} \sum_{t=1}^{N_t} \left(1 - K_{y,i,c,t} \left(1 - \frac{R_{i,c,t}}{D_{i,c,t}}\right)\right) - M \left(\frac{SP_t}{SP_c}\right)
\]

Where \(i,c,t\) are the indexes corresponding to canal, crop and time period and \(M\) is relatively large number for penalty. \(K_{y,i,c,t}\) is the yield response factors of respective crops in different intra-seasonal periods. \(R_{i,c,t}\) and \(D_{i,c,t}\) are actual amount of water allocated (Mm³) and maximum water demand (Mm³) of respective crops in different time periods. \(SP_t\) and \(SP_c\) are the reservoir spill in time period \(t\) and capacity of the spillway respectively.

The following is the list of constraints to be satisfied.

Minimum and maximum release to crop

\[
0.5D_{i,c,t} < R_{i,c,t} < D_{i,c,t} \quad \forall t
\]

Where \(R_{i,c,t}\) is the release to a particular crop in a particular time period under any canal.

Water release for irrigation

Considering irrigation losses, reservoir releases into the canals for irrigation are given by,
\[ R_{1,t} = \frac{\sum_{c=1}^{N_c} \sum_{t=1}^{N_t} R_{1,c,t}}{\eta_c} \quad \forall t \]  
\[ R_{2,t} = \frac{\sum_{c=1}^{N_c} \sum_{t=1}^{N_t} R_{2,c,t}}{\eta_c} \quad \forall t \]

Where \( R_{1,c,t} \) and \( R_{2,c,t} \) are the amount of water to be allocated at field level to various crops in a particular fortnight under left and right main canal command areas respectively. \( \eta_c \) is the canal efficiency and it is taken as 0.6 in the present study.

**Upper bounds on canal flow**

\[ R_{1,t} \leq C_{max} \quad \forall t \]  
\[ R_{2,t} \leq C_{max} \quad \forall t \]

Where \( C_{max} \) is maximum allowable flow into left and right canals.

**Active Storage bounds**

\[ 0 \leq S_t \leq S_{max} \quad \forall t \]

Where \( S_{max} \) is the maximum reservoir live storage.

**Lower and Upper bounds on d/s releases**

\[ R_{dmin} \leq R_{d,t} \leq R_{dmax} \quad \forall t \]

Where \( R_{d,t} \) is the d/s releases in period \( t \), \( R_{dmin} \) and \( R_{dmax} \) are the minimum and maximum d/s releases.

**Reservoir storage continuity**

\[ (1+a_t)S_{t+1} = (1-a_t)S_t + I_t - (R_{1,t} + R_{2,t} + R_{d,t}) - SP_t - A_e \epsilon_t \quad \forall t \]

Where \( a_t = \frac{a \epsilon_t}{2} \)

Where \( I_t \), \( S_t \) and \( \epsilon_t \) are the reservoir inflow, storage and rate of evaporation in time period \( t \).

\( R_{1,t} \) is the aggregate left canal irrigation release and \( R_{2,t} \) is aggregate right canal irrigation release in period \( t \), \( R_{d,t} \) is the release in Mm$^3$ from the reservoir to river downstream side (d/s), \( A_e \) is reservoir water spread area at minimum drawdown level. \( a \) is reservoir water surface area per Mm$^3$ of live storage.

**Steady state storage condition**

To obtain steady state reservoir operating policy, the initial reservoir storage in consecutive years should be same.

\[ S_{25} = S_1 \]

The above presented model is executed and policies are obtained by considering 75%, 80% & 85% dependable inflows into the reservoir.
4. Results and Discussions

The model presented in the above section is demonstrated through a case study of Nagarjunasagar reservoir project using GA as well as GA – NLP models independently by MATLAB software. The values of GA parameters population size, crossover probability and number of generations are adopted as 100, 0.8 and 500 respectively. Fitness value with GA model is obtained as -17.24 while it is -13.07 with GA-NLP hybrid approach for 75% dependable inflow. The same results obtained for other dependable inflows. The above result reveals that GA-NLP hybrid approach is more efficient when compared to GA for obtaining global optimal solution, minimizing the number of trial runs by changing the values of GA parameters.

Optimal policies are obtained by running the model for 75%, 80% & 85% dependable inflows. Variations of fortnight reservoir active storages for all three cases of inflow are shown in figure 3. It shows that the reservoir storage is increasing from AUG to NOV because of the monsoon inflows into the reservoir and there after it is getting depleted in all three cases. Minimum initial storages to be maintained for steady state reservoir operation are observed to be 166.536 MCM, 682.27 MCM and 776.038 MCM for 75%, 80% & 85% dependable inflows respectively. It is observed that carry over year storage is high in second and third cases because the inflows are lower.

![Figure 3. Optimal initial active storages to be maintained in the reservoir with different levels of dependable inflow.](image)

Aggregate reservoir release demand ratios for all intra seasonal periods into the canals with 75%, 80% & 85% dependable inflows are shown in figures 4 and 5. For 75% PE inflows, deficit irrigation takes place only in JUL I, JUL II & OCT I fortnight and full irrigation is given for all remaining fortnights in left and right main canals command area as shown in figures 4 & 5.
A typical water allocations to different crops in NOV I fortnight under left main canal is shown in table 4 with 85% dependable inflow. Water is allocated considering yield response to water deficit. Deficit irrigations are given to Rice2 (K) and Grams (R) while full irrigations are given to the remaining crops considering the yield response factors. A typical optimal irrigation scheduling calendar for left main canal is shown in table 5 for 75% dependable inflow.
Table 4. Water Allocations to crops under NSLC in NOV I time period for 85% Inflow.

| Crop name   | Demand (MCM) | K_y | Allocated water (MCM) | % Irrigation |
|-------------|--------------|-----|-----------------------|--------------|
| Rice2 (K)   | 42.86        | 0.25| 21.428                | 50.00        |
| Cotton      | 5.28         | 0.5 | 5.280                 | 100.00       |
| Chilli      | 4.64         | 0.8 | 4.640                 | 99.97        |
| Groundnut (R) | 18.72     | 0.2 | 18.720                | 100          |
| Sorghum (R) | 35.77        | 0.2 | 35.770                | 100.00       |
| Grams (R)   | 36.37        | 0.05| 18.183                | 50.00        |

Table 5. Typical Optimal Irrigation Scheduling Calendar under NSLC with 85% Inflows.

| Fortnight | Rice 1 (K) | Rice 2 (K) | cotton | chilli | Groundnut (R) | Sorghum (R) | Grams (R) |
|-----------|------------|------------|--------|--------|---------------|-------------|-----------|
| JUL I     | 100.000    |            |        |        |               |             |           |
| JUL II    | 0.940      | 100.000    |        |        |               |             |           |
| AUG I     | 2.132      | 0.938      |        |        |               |             |           |
| AUG II    | 7.437      | 6.218      |        |        |               |             |           |
| SEP I     | 7.437      | 7.437      | 0.870  | 0.310  |               |             |           |
| SEP II    | 17.430     | 17.430     | 0.990  | 0.310  |               |             |           |
| OCT I     | 9.856      | 17.430     | 3.010  | 2.350  |               |             |           |
| OCT II    | 21.428     | 3.010      | 2.340  | 8.300  | 16.610        | 8.305       |
| NOV I     | 5.280      | 4.640      | 18.720 | 35.770 | 18.183        |             |
| NOV II    | 5.280      | 4.640      | 21.010 | 37.050 | 19.418        |             |
| DEC I     | 6.280      | 5.590      | 26.260 | 45.320 | 47.910        |             |
| DEC II    | 5.900      | 5.590      | 26.260 | 45.320 | 47.910        |             |
| JAN I     | 5.200      | 4.900      | 26.560 | 45.840 | 48.450        |             |
| JAN II    | 4.430      | 23.500     | 35.800 | 30.415 |              |             |
| FEB I      |            |            |        |        | 22.950        |             |

Reservoir simulation is performed adopting developed GA-NLP optimal policy as well as Standard Operating Policy (SOP) with the historic inflow data. The performance is evaluated by finding Reliability & Relative yield. Table 6 shows the Performance parameters of simulation results obtained by developed policy as well as SOP during drought period and are found to be better when compared to that of SOP. This shows that the policy developed is performing well when compared to SOP during drought periods.
Table 6. Simulation results of GA-NLP & SOP during drought period.

| Performance parameter | GA-NLP | SOP |
|------------------------|--------|-----|
| Average relative yield | 0.356  | 0.332 |
| Reliability of meeting irrigation demands | 0.666  | 0.611 |

5. Conclusion
In this study, steady state multi-objective reservoir operating policies are developed by GA–NLP hybrid approach. Fortnight reservoir releases for irrigation are obtained for different priorities by giving appropriate weightages in the objective function. Reservoir irrigation releases are integrated with fortnight crop water allocations considering yield response to water deficit maximizing the relative yield. Fortnight wise reservoir storages, releases &crop water allocation are obtained with different levels of dependable inflows entering into the reservoir. Optimal solution can be obtained by GA-NLP hybrid approach reducing the number of trial values of GA parameters when compared to GA model. Optimal policies derived by the developed models are validated through simulation and compared with SOP considering drought period. The policies developed are performing well when compared to SOP during drought periods. The above model demonstrates that GA-NLP hybrid approach can be applied successfully for deriving multi-purpose reservoir operating policies.

References
[1] Yeh W 1985 Water Resour. Res. J. 21 1797–1818
[2] Oliveira R and Loucks D P 1997 Water Resources Research 33 839–852
[3] Labadie J W 2004 J. Water Resources Planning and Management 130 93–111
[4] Chavez-Morales J, Marino M A and Holzapfel E A 1987 Journal of Irrigation and Drainage Engineering, 113 549–564
[5] Srinivasa Prasad A, Umamahesh N V and Viswanath G K 2011 Irrigation and Drainage Systems 25 19-38
[6] Srinivasa Prasad A, Umamahesh N Vand Viswanath G K 2006 Journal of Irrigation and Drainage Engineering 132 228-237
[7] Umamahesh N V and Sudarsan Raju S 2002 Proc., Advances in Civil Engineering (IIT-Kharagpur, India)
[8] Vedula S and Mujumdar P P 1992 Water Resources Research 28 1–9
[9] Vedula S and Nagesh Kumar D 1996 Water Resources Research 32 1101–08
[10] Hosseinpourtehrani M & Ghahraman B 2002 Asian Journal of Applied Sciences 4 493-513
[11] Safavi H R, Alijanian M A 2011 Journal of Irrigation and drainage engineering 137 383-397
[12] Srinivasa Prasad A, Umamahesh N V and Viswanath G K 2013 Journal of Water Resources Planning and Management 139 149-158
[13] Fahmy H S, King J P, Wetzel M W, and Seton J A 1994 Paper No.943034, Int. Summer Meeting, (American Society Of Agricultural Engineers, St. Joseph, Mich)
[14] Wardlaw R & Sharif M 1999 Journal of Water Resources Planning and Management 125 25–33
[15] Labadie J W 2004 J. Water Resources Planning and Management 130 93–111
[16] Nagesh Kumar D, Raju K S & Ashok B 2006 Journal of Irrigation and Drainage Engineering 132 123–129
[17] Jothiprakash V and Shanthi G 2006 Water Resources Management 20 917–929
[18] Hashemi M S, Barani G A, and Ebrahimi H 2008 Journal of Applied Sciences 8 2173–77
[19] Haq and Anwar 2010 Journal of Irrigation and Drainage Engineering 136 704-714
[20] East V & Hall M J 1994 Proc., 1st Int. conf. on hydro-informatic (Balkema Rotterdam, The Netherlands) pp 225–231
[21] Hincal O, Altan Sakarya A B and Ger A 2010 Water Resources Management 25 1465–1487
[22] Kim T, Heo J H and Jeong C S 2006 Hydrological Processes 20 2057–75
[23] Janga Reddy M & Nagesh Kumar D 2006 Water Resour. Manag. 20 861–878
[24] Li X G and Wei X 2008 Water Resources Management 22 1031–49
[25] Yengui F, Labrak L, Frantz F, Daviot R, Abouchi N & O’Connor I 2012 Circuits and Systems 3 146-152
[26] Goldberg D E 2000 Genetic Algorithms in Search, Optimization, and Machine Learning (Addison-Wesley-Longman, Reading, Massachusetts, USA)
[27] Ravindran A, Phillips D T and Solberg J J 2001 Operations Research – Principles and Practice (John Wiley & Sons, New York)
[28] Taha H A 2005 Operations Research – An Introduction (Prentice-Hall of India Pvt. Ltd., New Delhi)
[29] Doorenbos J & Kassam A H 1979 FAO Irrigation and Drainage Paper 33
[30] Doorenbos J & Pruitt W 1977 FAO Irrigation and Drainage paper 24