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Management of Multipurpose Multireservoir Using Fuzzy Interactive Method

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Abstract In this paper a fuzzy interactive method is proposed for efficient management of multipurpose multireservoir problems. The proposed method provides an option to decision maker (DM) to work in an interactive manner to achieve the conflicting objectives as close to their desired values as is practically feasible. In each iteration, fuzzy membership functions of various objectives are framed and combined into a single objective using the product operator. The single objective nonlinear optimization model thus framed in each iteration is numerically solved using genetic algorithm. The solution provides the values of the objectives which can be actually achieved keeping in view their aspired values as provided by DM. At the end of each iteration, DM has the option to modify the aspired values of one or more objectives keeping in view the results obtained by the algorithm thus far. The algorithm is stopped when DM feels satisfied with the results. The working of the proposed method has been demonstrated on the mathematical model of a realistic multipurpose multireservoir system taken from literature.

Keywords Reservoir operation · Multiobjective optimization · Fuzzy optimization · Interactive method · Irrigation and hydroelectric power generation

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1 Introduction

Reservoir operation is an important aspect of water resources planning and development. Each reservoir system has its own unique features and a variety of mechanisms that define its operating rules. The operation of a multipurpose reservoir system usually consists of conflicting requirements and usually several alternative practical operating scenarios exist. However, there is no standard format for specifying operating rules which are applicable to all the situations. The key to a successful management plan for any reservoir system, therefore, lies in decision maker's (DM) ability to select the right operating policy from amongst the alternative set of policies available given the expected inflows into the reservoir during the operation period.

Researchers, in the past, have applied different types of mathematical programming techniques such as linear programming, dynamic and non-linear programming, etc. to analyse reservoir operation problems. An extensive review of these techniques is given in Loucks et al. (1981), Yakowitz (1982), Yeh (1985) and Wurbs (1993). Multiobjective approaches has also been used to solve such problems. Approaches used for analysing reservoir operation problems may be broadly classified into three groups.

a) *a priori methods*. In these methods weights are assigned to different objectives, based on importance of the objectives. These are then converted into a single objective using a suitable operator such as weighted sum approach, compromise programming approach, etc,. Weighted sum approach using particle swarm optimization has been used by Kumar and Reddy (2007) for multipurpose multi-reservoir operation. In their model two objectives have been considered. These are: minimization of irrigation deficits and maximization of hydropower generation. Drawback of the weighted sum approach is that, if the objective functions are nonlinear, then we can not achieve all possible Pareto optimal solutions (Deb 2002). Moreover, assigning of weights to different objectives is also a difficult task.
b) *a posterior methods*. In these methods many Pareto optimal solutions are generated without specifying any preferences for the objectives, and from amongst the set of Pareto optimal solutions DM then chooses acceptable solution. Second generation evolutionary techniques, developed for multiobjective problems, also fall in this class. Multiobjective genetic algorithm (NSGA-II) (Reddy and Kumar 2006), Multiobjective ant colony optimization (Kumar and Reddy 2006), Multiobjective particle swarm optimization (Reddy and Kumar 2007a) and Multiobjective differential evolution (Reddy and Kumar 2007b) have been used for analysing multipurpose multireservoir system problems. Although, these techniques found a set of Pareto optimal solutions in single simulation and frequently used recently, but also have some limitations. The number of trade-off solutions found by these techniques are too many. However, in a real world scenario, it is desired to have not more than five to ten different candidate solutions from which one could be selected (Deb 2002). Therefore, further analysis is needed to choose acceptable solution. Also, as the number of objectives increases computational complexity of these techniques are increased, and analysis becomes difficult to choose single solution from a set of Pareto optimal solutions.

c) *Interactive method.* There are iterative processes in which decision maker has the option to incorporate (modify) his(er) preferences during the iterations of the optimization process. For detailed survey of such techniques one may refer to Miettinen (2002). Mohan and Nguyen (1998), and Sakawa and Yauchi (2001) have also developed fuzzy interactive method for multiobjective optimization problems. However, such fuzzy interactive methods have not been utilized for solution of reservoir management problems and there is a scope to apply these techniques to determine optimal policies for operating multipurpose reservoirs systems.

Recently, Regulwar and Raj (2008) have developed 3-D optimal surface for deciding operation policies of a multi reservoir modeled in fuzzy environment for river basin development and management. In their model, maximization of irrigation release and maximization of power production have been considered as the objectives. They have used a fuzzy based approach to solve this problem. In their approach, first a fuzzy goal is defined for each objective. Next, these goals are aggregated into single objective using non-compensatory min operator. The single objective optimization problem is finally solved using a genetic algorithm. However, the min operator used by them might not able to always achieve desired trade off of different Pareto optimal solutions.

In this paper we present another approach for analysing multipurpose reservoir problems. In the proposed method first user specifies his aspired goals for each objective keeping in view the actual requirements and constraints. Compensatory product operator is next used to aggregate different objectives. The single objective non-linear optimization problem thus formulated is next numerically solved using genetic algorithm, MI-LXPM recently developed by Deep et al. (2009). The algorithm tries to achieve the aspired values of the goals as closely as possible. It is interactive in nature and the user has the option to upgrade/modify his(er) aspired goals at each iteration.

2 Mathematical Model of the Problem

The schematic representation of the physical system which include Jayakwadi project stage-I (R_1), Jayakwadi project stage-II (R_2), Yeldari project (R_3), Siddheshwar project (R_4) and Vishnupuri project (R_5) is shown in Fig. 1. Relevant data of reservoirs such as their location, live and gross storage capacity, installed power generation capacity, maximum flow in turbines and irrigable command area are given in the Table 1, which is taken from Regulwar and Raj (2008). The irrigation demand and inflow are shown in Table 2. In the problem formulation for optimization, four reservoirs are there. The fifth reservoir is considered as downstream control and is incorporated as a constraint in the model.

2.1 Objective Function

The two objectives considered in this study are

1. Maximization of irrigation releases (RI).

$$Max\ f_1 = \sum_i \sum_j (RI)_{ij} \tag{1}$$

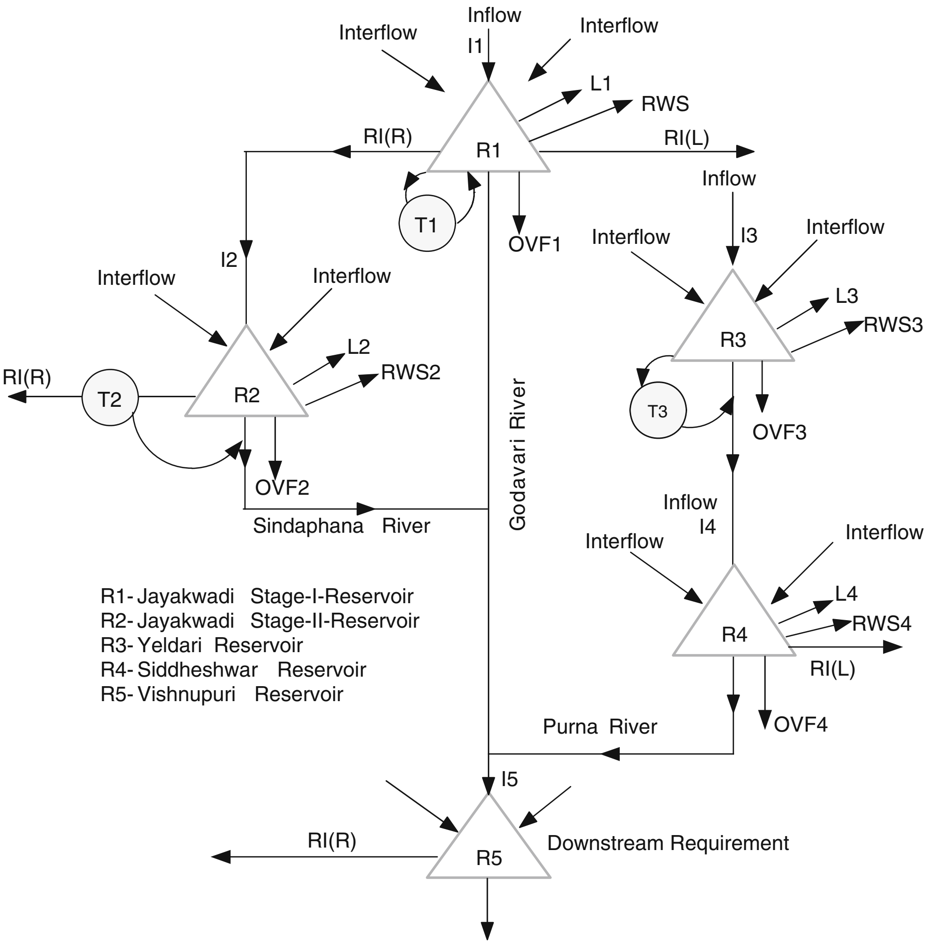


Fig. 1 Schematic representation of the physical system

Table 1 Data regarding reservoirs

Reservoir	Jayakwdi-I (R_1)	Jayakwdi-II (R_2)	Yeldari (R_3)	Siddheswar (R_4)	Vishnupuri (R_5)
Location (river)	Godavari	Sindaphana	Purna	Purna	Godavari
Live storage ($\times 10^6 m^3$)	2171	311.30	809.77	80 .96	–
Gross storage ($\times 10^6 m^3$)	2909	453.64	934.44	250.85	83.85
Area under FRL (Km^2)	350	78.86	106.83	40.58	–
Turbines no. and capacity ($\times 10^4 kWh$)	1 × 12	3 × 0.75	2 × 7.5	–	–
Turbine release capacity ($\times 10^6 m^3$)	07.52	411.48	960.0	–	–
Max. head (m)	32.3	7.10	38.10	–	–

Table 2 Maximum irrigation demand and inflow in reservoirs in $\times 10^6 m^3$

Month	Jayakwadi Stage-I (R_1)		Jayakwadi Stage-II (R_2)		Yeldari (R_3)	Siddheshwar (R_4)		Vishnupuri (R_5)	
	Irrigation demand	Inflow	Irrigation demand	Inflow	Inflow	Irrigation demand	Inflow	Irrigation demand	Inflow
Jun.	18.55	148.76	7.12	20.98	72.83	33.10	7.71	35.91	16.42
Jul.	26.70	408.25	20.83	43.46	141.09	35.23	2.21	22.97	35.96
Aug.	25.43	610.66	37.64	96.88	200.36	35.23	11.97	31.69	107.32
Sep.	85.79	600.0	46.02	144.17	160.77	93.46	9.18	31.49	246.07
Oct.	267.86	287.75	132.01	75.52	123.10	77.60	1.29	31.95	79.00
Nov.	228.74	196.46	127.05	10.24	49.48	74.68	0.57	22.68	9.91
Dec.	210.88	125.53	89.43	4.27	35.58	65.14	0.89	35.09	7.93
Jan.	230.34	37.65	100.68	0.37	32.18	65.14	1.00	38.46	1.13
Feb.	85.23	21.46	30.02	0.37	24.23	35.50	0.39	23.65	0.00
Mar.	70.06	19.56	28.98	0.16	23.54	37.40	1.00	14.50	0.00
Apr.	85.49	25.50	35.58	0.12	13.15	30.50	0.40	19.06	0.00
May	58.20	46.58	25.88	0.06	13.86	22.30	0.40	28.07	0.00

2. Maximization of hydro-power production (P)

$$Max\ f_2 = \sum_i \sum_j (P)_{ij} \tag{2}$$

where i varies from 1 to the number of reservoirs (four) and j varies from 1 to number of time steps (12 months). $P = 2,725 \times RP \times H$ kWh for a 30-day month.

2.2 Constraints

2.2.1 Turbine Release-Capacity

The releases into turbines for power production, should be less than or equal to the flow through turbine capacities (TC) for all the months.

$$RP(i, j) \leq TC(i), \quad \forall i = 1, 2, 3, 4; \quad \forall j = 1, 2, ..., 12. \tag{3}$$

Also, power production in each month should be greater than or equal to the firm power (FP). These constraints can be written as:

$$RP(i, j) \geq FP(i), \quad \forall i = 1, 2, 3, 4; \quad \forall j = 1, 2, ..., 12. \tag{4}$$

2.2.2 Irrigation Release-Demand

The releases into canals for irrigation (RI) should be less than or equal to the irrigation demand (ID) on all reservoirs for all the months.

$$RI(i, j) \leq ID(i, j), \quad \forall i = 1, 2, 3, 4; \quad \forall j = 1, 2, ..., 12. \tag{5}$$

Also, the releases into the canals for irrigation should be greater than or equal to the minimum irrigation demand (ID_{min}). In this study ID_{min} is taken as 30% of irrigation demand.

$$RI(i, j) \geq ID_{min}(i, j), \quad \forall i = 1, 2, 3, 4; \quad \forall j = 1, 2, ..., 12. \tag{6}$$

2.2.3 Reservoir Storage-Capacity

The storage in the reservoirs (S) should be less than or equal to the maximum storage capacity (SC) and greater than or equal to the minimum storage capacity (S_{min}) for all months. These constraints can be written as:

$$S(i, j) \leq SC(i), \quad \forall i = 1, 2, 3, 4. \tag{7}$$

$$S(i, j) \geq S_{min}(i), \quad \forall j = 1, 2, ..., 12. \tag{8}$$

2.2.4 Hydrologic Continuity

These constraints relate to the turbine releases (RP), irrigation releases (RI), release of water for drinking and industrial use (RWS) (which is taken as a constant), reservoir storage (S), inflows into the reservoirs (IN) and losses from the reservoirs for all months. The losses from the reservoirs are taken as function of storage as given by Loucks et al. (1981). The actual evaporation loss during the time period j is given by Evaporation loss $= A_0 e_j + a_j(S_j + S_{j+1})$, where A_0 is reservoir water surface area corresponding to the dead storage volume, e_j is evaporation rate corresponding to the time period j (in depth units), A_a is the reservoir water spread area per unit volume of active storage and $a_j = 0.5 A_a e_j$. The values of e_j in this study (in inch) from January to December are 5, 5, 11, 14, 13, 10, 8, 7, 7, 6, 5, 4.

The hydrologic continuity constraints for all the reservoirs can be written as:

1. Reservoir(R_1)

$$\begin{aligned}(1 + a_j(1, j))S(1, j+1) = {} & (1 - a_j(1, j))S(1, j) + IN(1, j) \\ & -RP(1, j) - RI(1, j) - OVF(1, j) - RWS(1, j) \\ & -FCR(1, j) + \alpha_1 RP(1, j) - A_0 e_j(1, j) \\ \forall j = 1, 2, ..., 12. & \end{aligned} \tag{9}$$

2. Reservoir(R_2)

$$\begin{aligned}(1 + a_j(2, j))S(2, j+1) = {} & (1 - a_j(2, j))S(2, j) + IN(2, j) \\ & -RP(2, j) - RI(2, j) - OVF(2, j) - RWS(2, j) \\ & +\alpha_2 FCR(1, j) - A_0 e_j(2, j) \\ \forall j = 1, 2, ..., 12. & \end{aligned} \tag{10}$$

3. Reservoir(R_3)

$$\begin{aligned}(1 + a_j(3, j))S(3, j+1) = {} & (1 - a_j(3, j))S(3, j) + IN(3, j) \\ & -RP(3, j) - OVF(3, j) - RWS(3, j) - A_0 e_j(3, j) \\ \forall j = 1, 2, ..., 12. & \end{aligned} \tag{11}$$

4. Reservoir(R_4)

$$\begin{aligned}(1 + a_j(4, j))S(4, j+1) = {} & (1 - a_j(4, j))S(4, j) + IN(4, j) \\ & +\alpha_4 RP(3, j) + \alpha_3 OVF(3, j) - RWS(4, j) \\ & -RI(4, j) - OVF(4, j) - A_0 e_j(4, j) \\ \forall j = 1, 2, ..., 12. & \end{aligned} \tag{12}$$

5. Reservoir(R_5)

$$\begin{aligned}DSREQ(j) = {} & C_1 OVF(1, j) + C_2 OVF(2, j) + C_3 OVF(4, j) \\ & +DSIN(j) + \alpha RP(2, j) \\ \forall j = 1, 2, ..., 12. & \end{aligned} \tag{13}$$

$$S(i, 1) = S(i, 13). \tag{14}$$

Equation 14 is essential to bring the state of the reservoir at the end of the year to the initial storage at the beginning of the next year.

Releases for water supply (RWS) are taken as constant for reservoir R_1 as $31.63 \times 10^6\ m^3$, $3.55 \times 10^6\ m^3$ for R_2 and $2.0 \times 10^6\ m^3$ for R_3 and R_4 for all months. Reservoir R_1 have a pumped storage scheme. The transition loss for pumping turbine releases back into the reservoir is taken as 10% of the turbine releases. Therefore, α_1 in the constraint is 0.9 for reservoir R_1. The transition loss for Feeder Canal Release (FCR) from R_1 to R_2 is taken as 10% of FCR. Therefore, α_2 in the constraint is 0.9 for reservoir R_2. The transition loss for overflow (OVF) from R_3 to reach to R_4 is taken as 10% of OVF. Therefore, α_3 in the constraint is 0.9 for reservoir R_4. The transition loss for turbine releases (RP) from R_3 to reach to R_4 is taken as 10% of RP. Therefore, α_4 in the constraint is 0.9 for reservoir R_4. The transition loss for turbine releases (RP) from R_2 to reach to R_5 is taken as 10% of RP. Therefore, α_5 in the constraint is 0.9 for reservoir R_5. The transition loss for overflow (OVF) from R_1 to reach R_5 is taken as 10% of OVF. Therefore, C_1 in the constraint is 0.9 for reservoir R_5. The transition loss for overflow (OVF) from R_2 to reach R_5 is taken as 10% of OVF. Therefore, C_2 in the constraint is 0.9 for reservoir R_5. The transition loss for overflow (OVF) from R_4 to reach R_5 is taken as 10% of OVF. Therefore, C_3 in the constraint is 0.9 for reservoir R_5.

3 Interactive Method

The objectives (1) and (2) of the mathematical model of the problem formulated in Section 2 are conflicting in nature. So, it may not be possible to simultaneously maximize both, and some sort of compromise solution may have to be achieved. Therefore, in order to solve this multiobjective problem, we propose to use the following interactive method. This interactive method has two phases: (I) Calculation phase, and (II) dialogue phase which involves interaction with the DM. In each iteration, the procedure presents the DM some alternatives which are potential for being considered the best possible compromise solution. Based on information contained in these alternatives, the DM takes decision which (s)he feels is the best amongst alternatives provided (dialogue phase). This information is next used to adjust the preference parameters used in scalarizing the functions. A new optimization problem is, then, again solved (calculation phase). After some iterations the search process is stopped when the DM is satisfied. Based on this solution the final decisions are taken. Such types of interactive methods are currently available in the literature. They differ from each other in the way the multiobjective problem is transformed into a single objective optimization problem, the manner in which the information is provided by the DM, and the search technique (optimization technique) which is used to solve the single objective optimization problem formulated in each iteration.

In our proposed fuzzy interactive method each objective is solved first individually to determine the maximum and minimum values which it can achieve subject to the constraints to the problem. This information is then used to specify fuzzy membership function μ_{f_i} for this objective as under

$$\mu_{f_i} = \begin{cases} 1, & f_i \geq M_i\,; \\ \dfrac{f_i - m_i}{M_i - m_i}, & m_i \leq f_i \leq M_i; \\ 0, & f_i \leq m_i; \end{cases} \tag{15}$$

where m_i and M_i are the minimum and maximum values of this objective which are acceptable to DM (Usually $f_{i,min} \leq m_i \leq M_i \leq f_{i,max}$, where $f_{i,min}$ is the minimum and $f_{i,max}$ is the maximum possible values individually achievable by the ith objective, subject to specified set of constraints of this problem). The proposed membership function Eq. 15 assures that only values in the acceptable range (m_i, M_i) are considered and preference increasing from m_i to M_i in a linear manner. Shape of μ_{f_i} is depicted graphically in Fig. 2. The values m_i and M_i for ith objective are chosen by DM on the basis of his(er) knowledge of the realistic problem. According to Bellman and Zadeh (1970), various objectives are then aggregated into a single objective using product operator and written as:

$$Max \prod_{i=1}^{n} (\mu_{f_i}), \tag{16}$$

where n is number of objectives. DM's preferences, at each interactive phase, is incorporated as the minimum satisfaction level (reservation level) for each objective. It is incorporated as an additional constraint for each objective, to make sure that the minimum satisfaction level is achieved. With this the mathematical model of single objective optimization problem to be solved in each iteration becomes:

$$\begin{aligned} & Max \prod_{i=1}^{n} (\mu_{f_i}) \\ & Subject\ to \\ & \mu_{f_i} - \bar{\mu}_{f_i} \geq 0, \quad \forall\, i \in n, \end{aligned} \tag{17}$$

as well as all the constraints of the problem. Here, $\bar{\mu}_{f_i}$ is minimum reservation level specified on the basis of aspirations of DM which is desired to be achieved for ith objective. Its value has to be between 0 and 1. At each interactive phase DM may change his(er) specified reservation level, for some or all objective functions, on the basis of outcome of previous iteration. The process is repeated iteratively till DM is satisfied with the results. This Pareto optimal solution is expected to meet DM's aspirations to the extent possible under the constraints of the problem.

In order to solve nonlinear constrained optimization problem Eq. 17, in each interactive phase, real coded genetic algorithm, MI-LXPM (Deep et al. 2009), is used.

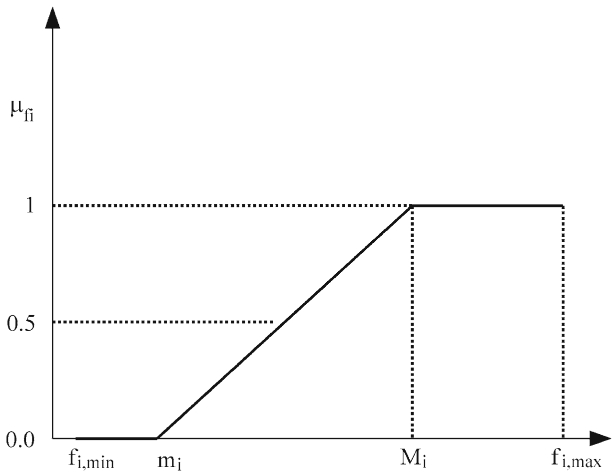


Fig. 2 Graphical representation of fuzzy goal

3.1 MI-LXPM Algorithm

MI-LXPM is a real coded genetic algorithm in which modified Laplace crossover and Power mutation operators with tournament selection operator are used. In this algorithm a truncation procedure is also used for those variables which have integer

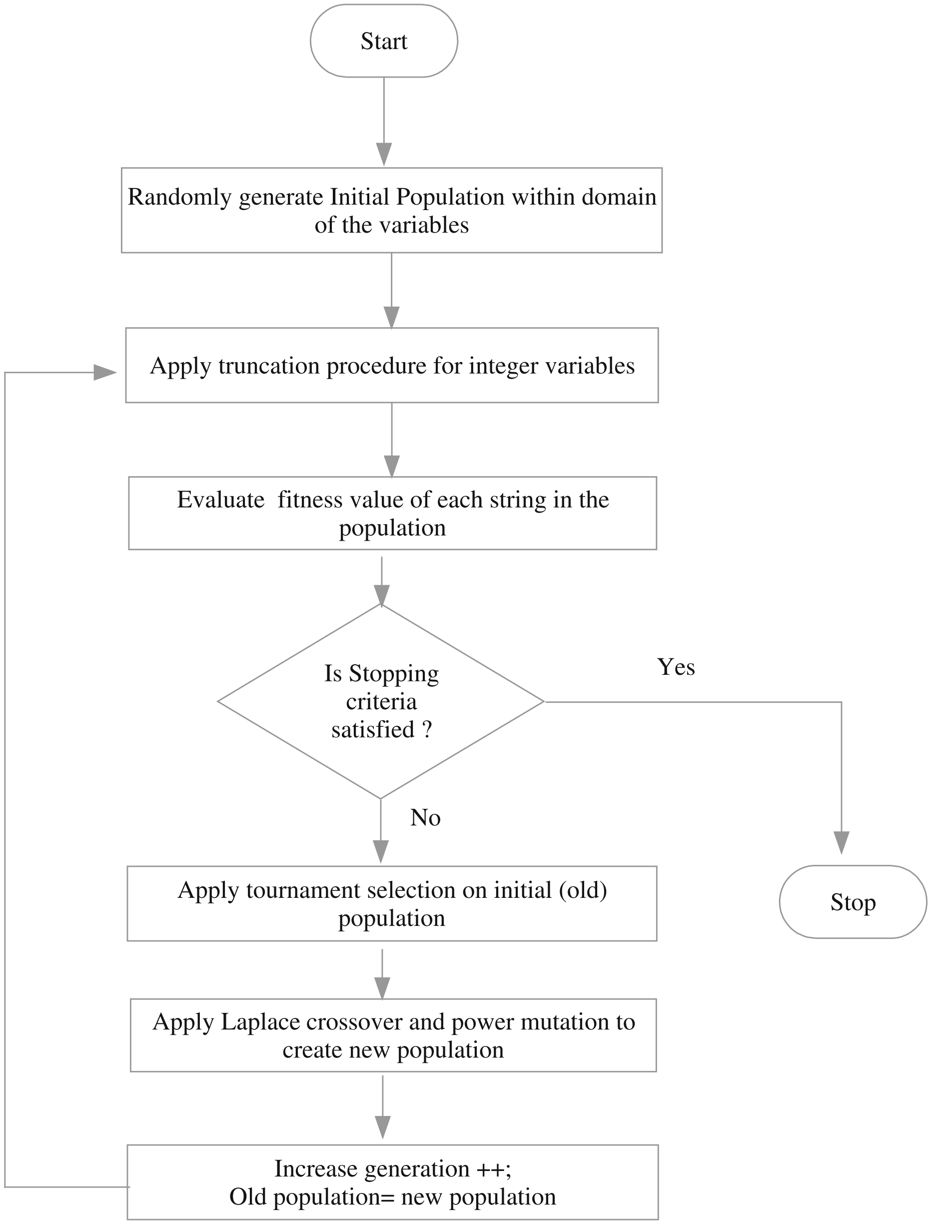


Fig. 3 Flow chart of MI-LXPM algorithm

restrictions and parameter free penalty approach is used for constraint handling. In different real life applications parameters setting are needed to be fine tuned. So, parameters setting used in this application are given in the computational steps of MI-LXPM algorithm. The flow chart of MI-LXPM is given in the Fig. 3. Main computational steps of MI-LXPM algorithm are as follows:

Step-1 Generate a suitably large initial set of random points within the domain (5 times to the number of decision variables), satisfying integer restrictions on variables where applicable and evaluate their fitness values.

Step-2 Check the stopping criteria (fix number of generations 5000). If satisfied stop else goto 3.

Step-3 Apply tournament selection (with tournament size 3) to decide which of these individuals are to be in mating pool.

Step-4 Apply Laplace crossover to all individuals in mating pool with probability of crossover($p_c = 0.8$).

Step-5 Apply Power mutation to all individuals in mating pool with probability of mutation ($p_m = 0.005$).

Step-6 Increase generation by one; goto 2.

4 Computational Results

The problem described in Section 2 is solved using interactive method given in Section 3. First each objective was solved separably for maximization and minimization subject to the constraints of the problem. On the basis of these values, let acceptable range for these objectives ($[m_i, M_i]$) are:

$$m_1 = 1822.4\ \times 10^6 m^3, \qquad M_1 = 2474.64\ \times 10^6 m^3, \quad \textit{irrigation release}$$

$$m_2 = 54730\ \times 10^4 kWh, \qquad M_2 = 123773\ \times 10^4 kWh, \quad \textit{power production}$$

Using Eq. 15 fuzzy membership functions μ_{f_1} and μ_{f_2}, respectively for irrigation release and power production are defined as:

$$\mu_{f_1} = \begin{cases} 1, & f_1 \geq 2474.0\,; \\ \dfrac{f_1 - 1823.0}{2474 - 1823}, & 1823.0 \leq f_1 \leq 2474.0; \\ 0, & f_1 \leq 1823.0; \end{cases} \tag{18}$$

and

$$\mu_{f_2} = \begin{cases} 1, & f_2 \geq 120000.0\,; \\ \dfrac{f_2 - 60000.0}{120000 - 60000}, & 60000.0 \leq f_2 \leq 120000.0; \\ 0, & f_2 \leq 60000.0. \end{cases} \tag{19}$$

Equation 18 implies that the DM will be fully satisfied if water released for irrigation is more than $2474 \times 10^6 m^3$ and will not like it to be less than $1823 \times 10^6 m^3$ in any case. His(er) satisfaction level increases from 0 to 1 linearly as the amount of water release for irrigation purpose increases from $1823 \times 10^6 m^3$ to $2474 \times 10^6 m^3$. Similarly, Eq. 19 means that DM will be fully satisfied if power generation is more than $120000 \times 10^4 kWh$ and will not like it to be less than $60000 \times 10^4 kWh$ in any

Table 3 Solution of problem

Iteration	I	II	III	IV	V
DM's specifications					
$\bar{\mu}_{f_1}$	0.30	0.70	0.80	0.90	0.75
$\bar{\mu}_{f_2}$	0.30	0.30	0.30	0.30	0.70
Solutions					
μ_{f_1}	0.647	0.70	0.80	0.90	0.75
μ_{f_2}	1.0	0.79	0.69	0.47	0.74
f_1	2243.94	2278.95	2344.37	2408.96	2311.9
f_2	120083	107405	101634	88436.8	104561

case. His(er) satisfaction level increasing linearly from 0 to 1 as the amount of power generation increases from $60000 \times 10^4 kWh$ to $120000 \times 10^4 kWh$. We now present results of the iterative process for solving it in which DM wants to achieve as large satisfaction in achievement of the values of both the objectives to their maximum aspired values as possible. For this (s)he makes some alternate choices. Suppose (s)he first starts with a rather low initial level of reservation as 0.3 for each objective ($\bar{\mu}_{f_1} = \bar{\mu}_{f_2} = 0.30$) (user can start with any other set of values between 0 and 1). The details of the solution obtained are as listed in iteration I of Table 3. Results show that $(f_1, f_2) = (2243.94, 120083)$ with membership values $(\mu_{f_1}, \mu_{f_2}) = (0.647, 1.0)$. This gives him hundred percent satisfaction with the second objective but only around 65% with the first objective. Suppose now in order to increase level of satisfaction of first objective (making its value closer to highest value aspired for it) (s)he restarts the iterative process with the $\bar{\mu}_{f_1} = 0.70$ and $\bar{\mu}_{f_2} = 0.30$. This yields him the results listed in iteration II of the Table 3. Still not satisfied (s)he makes another trial. (S)He continues like this till (s)he is satisfied with the results achieved. In the present case we have stooped at 5th iterations. Outcome of 5th iteration is $(f_1, f_2) = (2311.9, 104561)$ with membership values $(\mu_{f_1}, \mu_{f_2}) = (0.75, 0.74)$. This result shows

Fig. 4 Achieved membership value of irrigation release and power production in different iteration

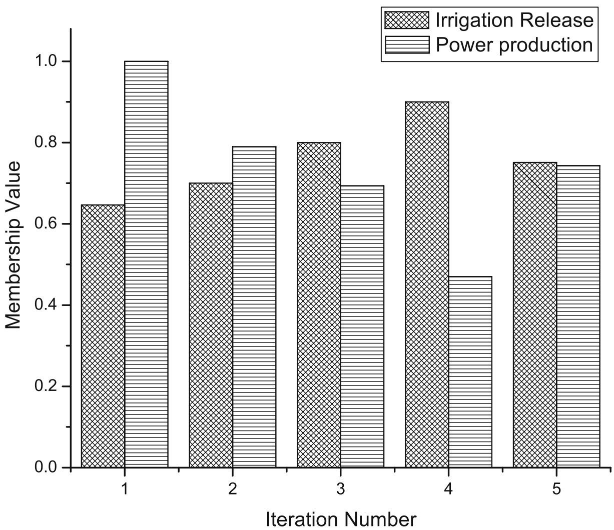
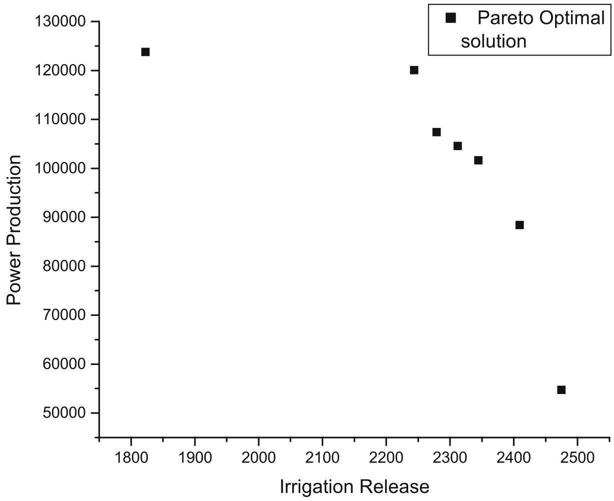


Fig. 5 Pareto optimal solution



75% achievements for irrigation release and 74% satisfaction for specified objective for power generation. DM now knows that s(he) can not improve value of one objective without reducing value of the other. Being satisfied with the results the iterative process is now stopped. A comparison of these results listed in the table with the results earlier obtained by Regulwar and Raj (2008) show that our results in iteration II are comparable to their results.

Figure 4 shows the graphical representation of achieved membership value of each objective (Irrigation release and Power production) in each interactive phase. It shows that as we move from iteration 1 to 5 the amount for irrigation release increases at the cost of amount of power generation and viceversa. Figure 5 shows the trade-off graph between irrigation release and power production.

Fig. 6 Monthly irrigation release from reservoir R_1, R_2 and R_4 corresponding to 5th iteration

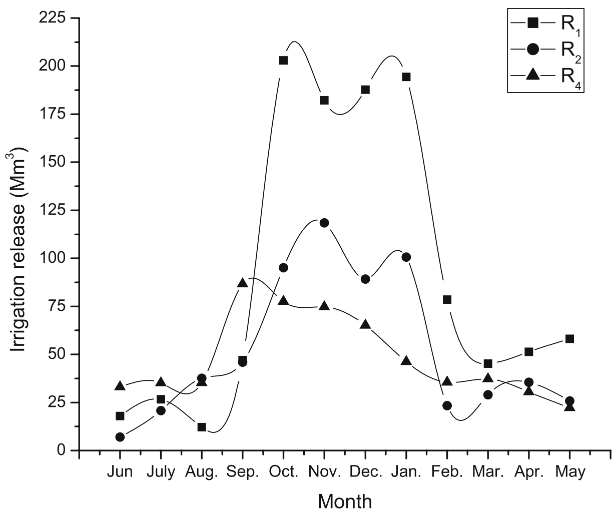


Fig. 7 Monthly power production from turbine T_1, T_2 and T_3, which are on reservoir R_1, R_2 and R_3, corresponding to 5th iteration

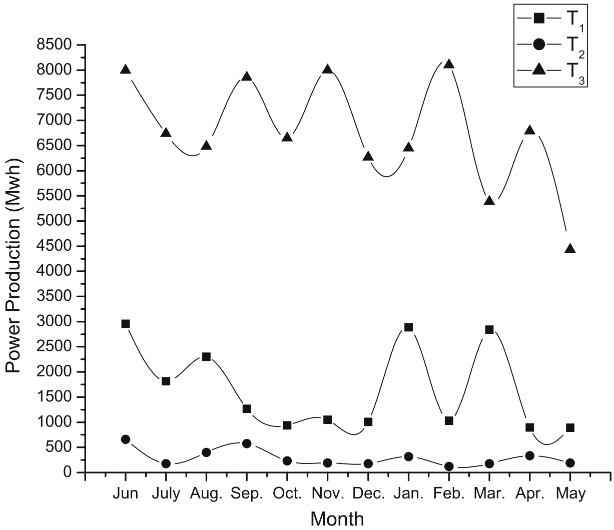


Fig. 8 Monthly storage of water in reservoir R_1, R_2, R_3 and R_4 corresponding to 5th iteration

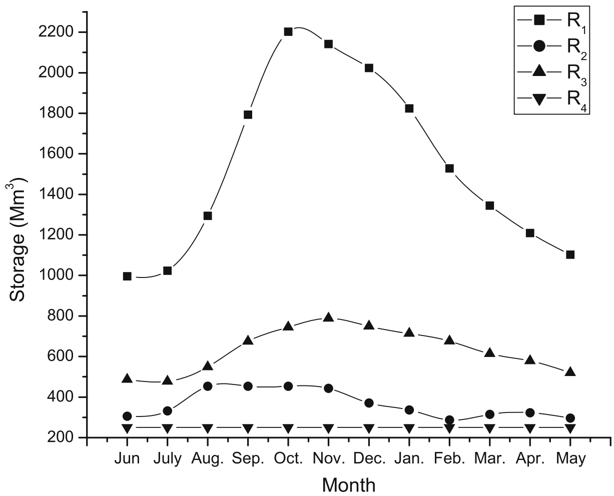


Table 4 Monthly irrigation release and power production

Month	Irrigation release ($\times 10^6 m^3$)			Power production ($\times 10^4 kWh$)		
	R_1	R_2	R_4	T_1	T_2	T_3
Jun.	17.8811	7.05247	33.0413	2955.0833	661.46679	7992.3164
Jul.	26.6084	20.7494	35.1194	1816.3594	177.67145	6736.3665
Aug.	12.2189	37.6349	35.2276	2303.591	401.54416	6480.3143
Sep.	47.0387	46.019	86.6674	1265.7172	576.53556	7854.0363
Oct.	202.998	95.1196	77.5751	935.5752	229.95197	6648.6662
Nov.	182.18	118.444	74.6785	1049.3259	190.99704	7997.0234
Dec.	187.763	89.2343	65.1288	1005.9517	178.35884	6267.9129
Jan.	194.369	100.679	46.2141	2886.7601	315.48338	6446.4782
Feb.	78.4715	23.3542	35.4969	1031.919	118.7387	8101.9458
Mar.	45.1656	28.9784	37.1754	2841.1734	177.44152	5387.0638
Apr.	51.3469	35.5745	30.4954	893.9313	332.95458	6789.1793
May	58.1417	25.7614	22.2989	890.9531	190.21746	4432.451

Table 5 Monthly storage of water in the reservoirs R_1, R_2, R_3, R_4 and discharge requirement in reservoir R_5

Month	Storage ($\times 10^6 m^3$)				D/S req.
	R_1	R_2	R_3	R_4	R_5
Jun.	995.73	305.501	487.177	250.85	52.42
Jul.	1023.64	331.45	477.644	250.85	135.53
Aug.	1293.82	453.64	548.374	250.85	161.52
Sep.	1792.88	453.64	675.293	250.85	503.44
Oct.	2202.39	453.64	745.166	250.85	154.65
Nov.	2142.24	443.397	788.89	250.85	77.32
Dec.	2023.84	370.824	749.099	250.85	74.97
Jan.	1824.23	336.837	714.255	250.85	56.91
Feb.	1527.75	286.902	675.738	250.85	52.02
Mar.	1344.83	314.147	613.688	250.85	52.15
Apr.	1209.57	323.021	578.332	250.85	42.30
May	1102.14	296.282	520.266	250.85	57.45

In Fig. 6 the monthly irrigation release from reservoirs R_1, R_2 and R_4 corresponding to 5th iteration are shown. Figure shows that maximum release of water for irrigation are in the months October, November, December and January. This may be an acceptable scenario since demand for irrigation is higher in these months. Months of June, July, August and September are rainy season. Therefore, demands of water for irrigation is less in these months. Monthly power production from turbines T_1, T_2 and T_3, which are on reservoirs R_1, R_2 and R_3, corresponding to 5th iteration are shown in Fig. 7. Figure shows that the maximum power production is from T_3, which is on R_3. Since, reservoir R_3 is only for power production, hence solution is satisfactory. Turbines T_1, T_2 are on reservoirs R_1, R_2, respectively, which are multipurpose reservoirs (that is, irrigation and power production). Power production from these are less than that from T_3. Figure 8 shows, monthly storage of water in reservoirs R_1, R_2, R_3 and R_4. Graph shows that the storage are maximum in the months August, September, October, and November as inflows are higher in these months due to rain, so the obtained results are acceptable. Irrigation release and power production based on 5th iteration are shown in Table 4 and monthly storage and downstream requirements for reservoirs are shown in Table 5.

5 Conclusions

In this paper, a fuzzy interactive method is proposed for obtaining solution of multipurpose multireservoir management problems. A multireservoir system in Godavari river sub basin in Maharashtra State, India is considered for this study. We have obtained alternative possible Pareto optimal policies using different preferences of DM. The iterative process is stopped at iteration 5 when DM observes that values of both the objectives are close to 75% of their individually possible maximum values. The main advantage of the proposed interactive method is that DM can achieve a possible optimal solution quite close to his(er) aspired values for the objectives and can therefore help decision maker in finding a solution as close to his(er) satisfaction as is practically feasible. Method also provides DM to modify/update aspired values of each objective in each iteration.

Notation

The following symbols are used in this paper

DSREQ(j)	Downstream requirement during month j;
DSIN(j)	Downstream inflow during month j;
FRL	Full Reservoir Level;
FCR(i,j)	Feeder Canal Releases during month j from reservoirs i;
FP(i,j)	Flow for firm power during month j from reservoirs i;
ID(i,j)	Maximum irrigation demand during month j from reservoirs i;
IDmin(i,j)	Minimum irrigation requirement during month j from reservoirs i;
IN(i,j)	Monthly inflow into the reservoir during month j from reservoirs i;
L	Evaporation Loss from reservoir;
OVF(i,j)	Overflow during month j from reservoirs i;
P(i,j)	Hydropower produced during month j from reservoir i;
RI(i,j)	Irrigation releases during month j from reservoirs i;
RP(i,j)	Releases for hydropower production in month j from reservoirs i;
RWS(i,j)	Water supply releases during month j from reservoirs i;
S(i,j)	Storage in the reservoir during month j from reservoirs i;
Smin(i)	Minimum storage capacity for ith reservoir;
SC(i)	Maximum storage capacity for ith reservoir;
T1, T2, T3	Turbines for reservoirs R1, R2 and R3;
TC(i)	Flow for maximum capacity of turbine from reservoirs i;
$\mu_i(x)$	Membership function of ith objective;
$\bar{\mu}_i$	Reservation level for ith objective;
$\alpha_1,\ \alpha_2,\ \alpha_3\ \alpha_4,\ \alpha_5$	Constants;
$C_1,\ C_2,\ C_3$	Constants.

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