



# Determining the Optimum Release Policy Through Differential Evolution: A Case Study of Mula Irrigation Project

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**Abstract.** The present study shows an implementation of Differential Evolution (DE) algorithm for determining the optimum flow policy for the reservoir operation. The case study is done for Mula Major Irrigation Project for river Mula (Godavari basin), Ahmednagar district, Maharashtra. The problem is formulated in terms of an unconstrained optimization model having 12 variables as the data collected is for one year.

**Keywords:** Differential Evolution · Reservoir operation · Release Storage

## 1 Introduction and Literature Review

Differential Evolution (DE) is most popular algorithm based on evolutionary algorithm which is developed by Price and Storn (1) for solving complex real life problem over different domains like continuous, discrete and combinatorial optimization problems. DE is easy to use, has a simple structure and has been applied to a wide variety of problems occurring in different domains. In the present study, DE is employed for determining the optimum release policy for reservoir operation. The case study is done for Mula river project, described briefly in Sect. 2. Some past instances of application of DE and its variants to reservoir operation problems are as follows:

The present study is divided into four sections first we introduce Differential Evolution and give the review of DE in reservoir problem, in second section we discuss the project of Mula river and In section third we discuss the results and lastly in section four we conclude our work.

### 1.1 Working of Differential Evolution

DE is works in two phases, first phase is initialization and the second phase is evolution. In first phase population is generated randomly and in the second phase, which is evolution, the generated population goes through mutation, crossover and selection process and the process is repeat until termination criteria is met.

**Table 1.** DE and its variants for reservoir problems.

Description	Reference
Short-term scheduling of hydrothermal power system with cascaded reservoirs by using modified differential evolution	Lakshminarasimman et al. (2)
Solving a reservoir problem using multi-objective differential Evolution	Reddy et al. (3)
Application of differential evolution for irrigation planning	Vasan et al. (4)
Evolving strategies for crop planning and operation of irrigation reservoir system using multi-objective differential evolution	Reddy et al. (5)
Short-term combined economic emission scheduling of hydrothermal power systems with cascaded reservoirs using differential evolution	Mandal and Chakraborty (6)
Multi-objective cultured differential evolution for generating optimal trade-offs in reservoir flood control operation	Qin et al. (7)
Differential evolution algorithm for optimal design of water distribution networks	Suribabu (8)
Optimization of water distribution network design using differential evolution	Vasan and Simonovic (10)
Differential evolution algorithm for solving multi-objective crop planning model.	Josiah and Otieno (9)
Differential evolution algorithm with application to optimal operation of multipurpose reservoir	Regulwar <i>et al.</i> (11)
Reservoir operation using multi-objective evolutionary algorithms-a review	Adeyemo (12)
Extraction of multi-crop planning rules in a reservoir system: application of evolutionary algorithms	Fallah-Mehdipour et al. (13)
Reservoir optimization in water resources: a review	Ahmad et al. (14)
Coupled self-adaptive multi-objective differential evolution and network flow algorithm approach for optimal reservoir operation	Schardong and Simonovic (15)
Fuzzy differential evolution method with dynamic parameter adaptation using type-2 fuzzy logic	Ochoa et al. (16)
A new approach for dynamic mutation parameter in the differential evolution algorithm using fuzzy logic	Ochoa et al. (17)
Differential evolution using fuzzy logic and a comparative study with other metaheuristics	Ochoa et al. (18)

(a) **Initialization:** During initialization, a set of uniformly distributed population is generated as follows:

Let  $S^G = \{X_j^G : j = 1, 2, \dots, NP\}$  be the population at any generation  $G$ ,  $NP$  denotes the size of population. Here,  $X_j^G$  denotes a  $D$ -dimensional vector as  $X_j^G = \{x_{1,j}^G, x_{2,j}^G, \dots, x_{D,j}^G\}$ .  $X_j^G$  is generated using uniformly distributed random number  $rand(0, 1)$

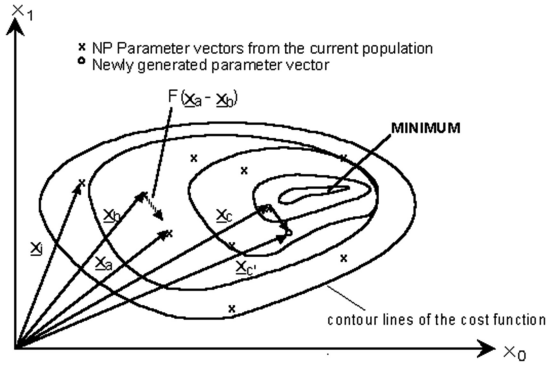


Fig. 1. Working strategy of differential evolution

$$X_j^G = X_{low} + (X_{upp} - X_{low}) * rand(0, 1) \tag{1}$$

Where  $X_{low}, X_{upp}$  are lower and upper bounds of search space  $S^G$ .

Once the initial population is generated, the next phase of evolution is activated.

- (b) **Evolution:** This is the second phase where mutation, crossover and selection operations are performed.

**Mutation:** In mutation we generate a mutant vector  $V_j^G$  for each target vector  $X_j^G$  at generation  $G$  as

$$V_j^G = X_{r1}^G + F * (X_{r2}^G - X_{r3}^G) \tag{2}$$

Where  $F$  is the scaling factor and value of  $F$  is vary from 1 to 0 and  $r1, r2, r3 \in \{1, 2, \dots, NP\}$  are mutually different, randomly chosen vectors.

**Crossover:** After mutation, crossover is done to generate a new vector called trial vector denoted as  $U_j^G = \{u_{1,j}^G, u_{2,j}^G, \dots, u_{D,j}^G\}$ . Crossover is performed between target vector  $X_j^G = \{x_{1,j}^G, x_{2,j}^G, \dots, x_{D,j}^G\}$  and mutant vector  $V_j^G = \{v_{1,j}^G, v_{2,j}^G, \dots, v_{D,j}^G\}$  using a crossover probability  $Cr$  whose value is between 0 to 1.  $U_j^G$  is generated as

$$u_{i,j}^G = \begin{cases} v_{i,j}^G & \text{if } rand_j \leq Cr \\ x_{i,j}^G & \text{otherwise} \end{cases} \tag{3}$$

Where  $i \in \{1, 2, \dots, D\}$  and  $Cr \in [0, 1]$ (Figs. 1, 2, 4, 5 and Table 1).

**Selection:** In this operation, a comparison is done between the target vector and trial vector according to their fitness value. The one having better fitness survives to the next generation. This operation is perform as:

$$X_j^{G+1} = \begin{cases} U_j^G & \text{if } f(U_j^G) \leq f(X_j^G) \\ X_j^G & \text{otherwise} \end{cases} \tag{4}$$

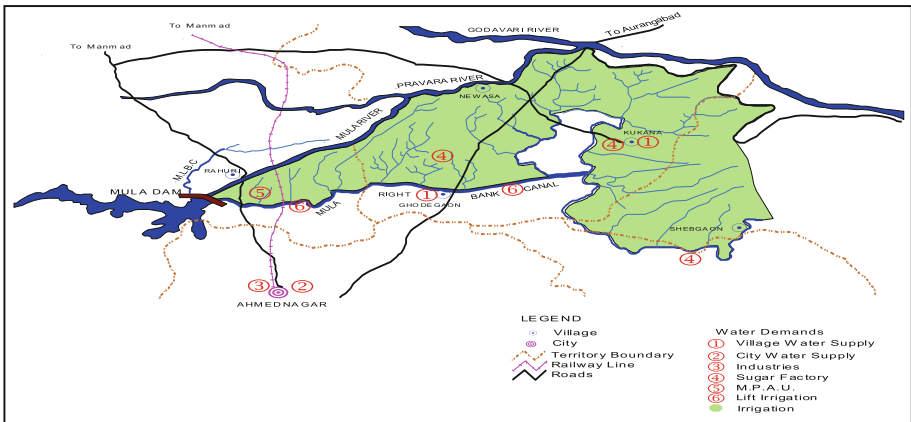
Mutation, Crossover and selection of evolution phase are repeated till a predefined termination criteria is satisfied.

**Pseudo code of Differential evolution:**

Generate initial population of size NP  
 Do while  
 For each individual j in the population  
 Generate three random numbers  $r1 \neq r2 \neq r3 \neq j$   
 For each parameter j, in the population  
 $X'_{i,j} = \begin{cases} X_{i,r3} + F * (X_{i,r2} - X_{i,r1}) & \text{if } rand_j \leq Cr \\ X_{i,j} & \text{otherwise} \end{cases}$   
 End for  
 Replace  $X_j$  with new particle  $X'_j$ , if  $X'_j$  is better  
 End For  
 Until the termination condition is satisfied

**2 Case Study**

The area of study selected is ‘Mula project’, a major irrigation project on the river Mula, tributary of Pravara, sub-tributary of Godavari. This multipurpose project provides irrigation water supply to Ahmednagar city and fulfils the water supply needs of industries and villages. It has two canals, right bank canal and left bank canal and distribution system to create an irrigation potential of 80,810 ha. Both the canals are perennial taking off from the reservoir. Average rainfall in this area is about 500 mm. in

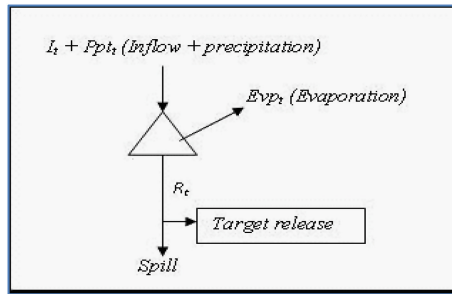


**Fig. 2.** Map of Mula project

lower catchment (but in upper catchment it is 5080 mm. which is sufficient). Major portion of irrigated land is black cotton soil. Evaporation is moderate.

### 2.1 Development of Reservoir Operation Models

The purpose of developing an optimal reservoir operation is to obtain a policy for regulating the water in a reservoir while satisfying the desired objectives. Here we assume that operating policy is composed of decision variable which is the release from the reservoir at each time period. The objective is to minimize the squared deviation of release from the target demands. Figure 3 shows a single reservoir system and the variables associated with a reservoir operation problem.



**Fig. 3.** Variables associated with a reservoir problem

There are upper and lower limits for releases and storages. These limitations form the constraints of the problem. Another constraint of the problem is due to continuity equation which is to be satisfied for each time period.

**Mathematical model:** In general a reservoir operation optimization problem may be expressed as

The objective function is:

Minimization of squared deviation from target demands

$$g_t(R_t) = \text{Min} \sum_{t=1}^N (Q_t - D_t)^2 \tag{5}$$

Where  $g_t(R_t)$  is function of release at time period  $t$ .  $Q_t$  is the release for period  $t$  and  $D_t$  is target demand for time period  $t$ .

Satisfy the continuity equation, which is stated as:

$$S_{t+1} = S_t + I_t - Q_t - Evp_t \forall t = 1, \dots, N \tag{6}$$

where  $S_t$ ,  $I_t$  and  $R_t$  are the storage, inflow and releases for the given reservoir at time period  $t$  and  $N$  is the time horizon for the problem under consideration.  $Evp_t$  is evaporation from reservoir surface during time period  $t$ , respectively.

Limits on storage impose constraints of the form

$$S_{min} \leq S_t \leq S_{max} \forall t = 1, \dots, N \tag{7}$$

This ensure that the storage ( $S_t$ ) will remain within specified minimum and maximum storages.

Limits on release

$$Q_{min} \leq Q_t \leq Q_{max} \forall t = 1, \dots, N \tag{8}$$

Where release ( $Q_t$ ) should be within specified minimum and maximum range.

Releases are the decision variables in the problem. Constraints of releases are identified during generation of initial population and as a matter of fact they are

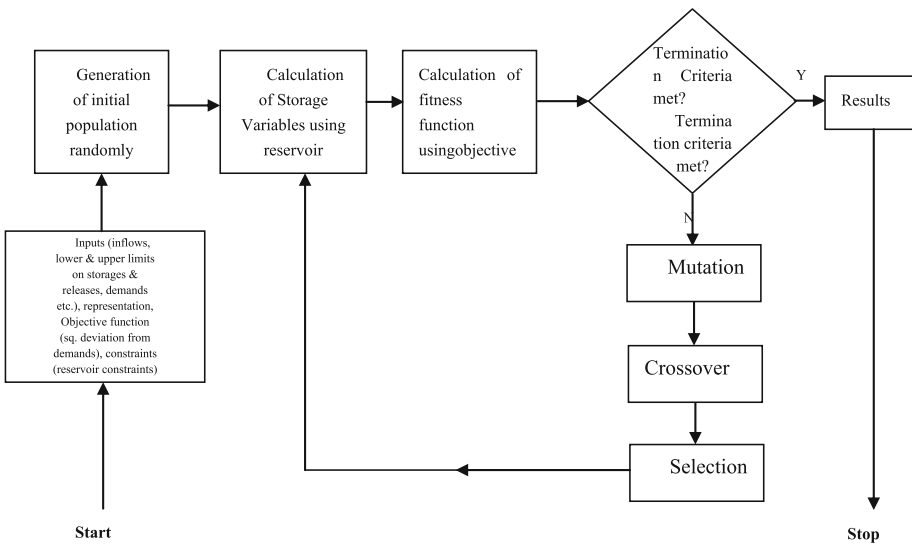


Fig. 4. Flowchart showing the steps used in reservoir operation optimization using DE

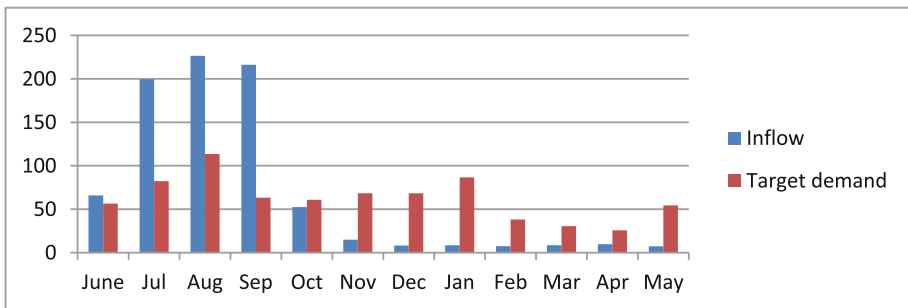


Fig. 5. Monthly inflow vs demand

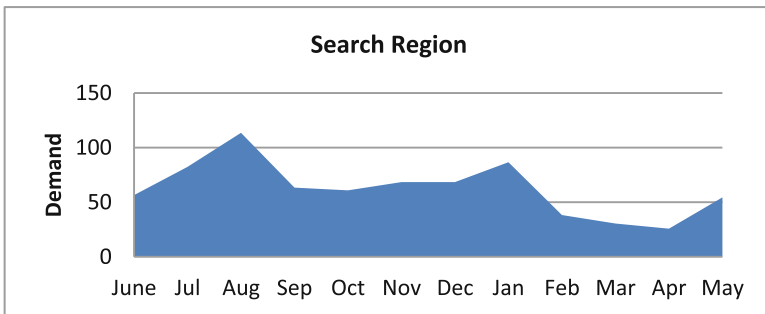
satisfied. Continuity equation is readily satisfied since the storages are computed by making use of continuity equation given in Eq. (6).

### 3 Experimental Settings

The present study is done for 12 months. There are two constraints in this problem on storage and release. Programming is done in MATLAB. The MATLAB program is run for  $NP = 20$  and  $Max\_Gen = 500$ . The program is run on computer with configuration of 16 GB RAM Intel(R) Xeon(R) CPU 3.50 GHz. The search area is shown in Table 2 and Fig. 6. The release of the problem is shown in Table 3 and Fig. 7

**Table 2.** Monthly release limits

Monthly release search limits		
Months	Lower limit	Upper limit
June	0	56.45
Jul	0	82.33
Aug	0	113.5
Sep	0	63.33
Oct	0	60.83
Nov	0	68.39
Dec	0	68.39
Jan	0	86.6
Feb	0	38.21
Mar	0	30.45
Apr	0	25.72
May	0	54.39



**Fig. 6.** Monthly demand

**Results of Reservoir Problem using Differential Evolution**

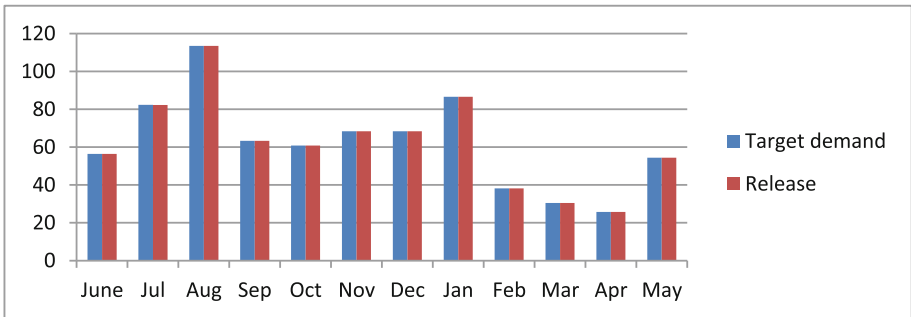
No. Of Generation = 500 Population size = 20

Objective value = 7.7017e-04 Time elapsed = 0.527234 s

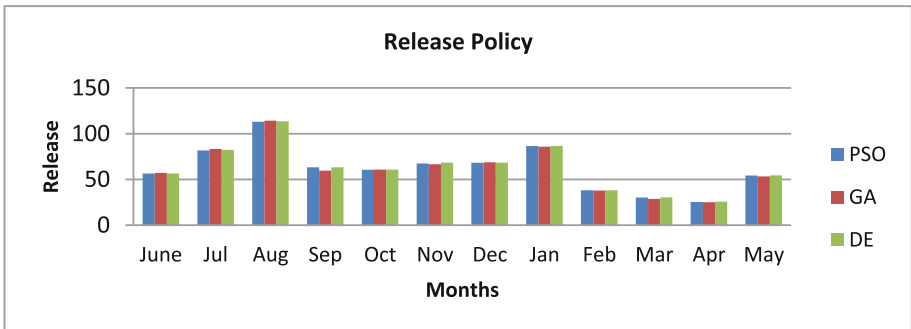
Release policies and Objective values of GA and PSO is shown in Table 4 and Comparison between DE, PSO and GA is shown in Fig. 8.

**Table 3.** Monthly release and storage using DE

Months	Initial storage	Inflow	Target demand	Release	Final storage	Evaporation	Spill	Irrigation deficit
June	0	65.8	56.45	56.44322	9.356778	0	0	0
Jul	9.356778	199.67	82.33	82.32011	122.9949	3.711747	0	0
Aug	122.9949	226.52	113.5	113.4864	231.7062	4.322333	0	0
Sep	231.7062	216.18	63.33	63.3224	377.8509	6.71292	0	0
Oct	377.8509	52.5	60.83	60.8227	363.7737	5.754469	0	0
Nov	363.7737	14.87	68.39	68.38179	303.3442	6.917752	0	0
Dec	303.3442	8.21	68.39	68.38179	237.512	5.660423	0	0
Jan	237.512	8.43	86.6	86.5896	154.7306	4.621793	0	0
Feb	154.7306	7.5	38.21	38.20541	119.8609	4.164317	0	0
Mar	119.8609	8.48	30.45	30.44634	93.65207	4.242443	0	0
Apr	93.65207	9.7	25.72	25.71691	72.10274	5.532417	0	0
May	72.10274	7.32	54.39	54.38347	19.03401	6.005257	0	0



**Fig. 7.** Release policy of reservoir using DE



**Fig. 8.** Comparison on release policy of DE, PSO and GA



**Table 4.** Release policies of GA and PSO

Release policy of GA and PSO		
Objective value	24.1421	3.88e-25
Time	3–4 s	3–4 s
Months	GA	PSO
June	57.15	56.43
Jul	83.28	82.32
Aug	114.18	113.3
Sep	59.64	62.96
Oct	60.74	60.73
Nov	66.6	68.39
Dec	68.67	68.34
Jan	85.75	86.5
Feb	37.87	38.19
Mar	28.75	30.46
Apr	25.03	25.7
May	53.32	54.35

## 4 Conclusion

This paper presents an application of DE for finding the optimum release policy for Mula river reservoir. The numerical results obtained by DE are compared with GA and PSO. It is observed that the release policy obtained by the three algorithms is more or less similar to each other but in terms of objective function value PSO and DE give much better results in comparison to GA. While in terms of computational time, DE gave the best results in comparison to the other two algorithms. In this paper the case study is done for a single year but as we increase the size of the problem, the complexity will also increase. Therefore presently the authors are working on modifying the DE/PSO algorithms for solving large scale reservoir problems.

## References

1. Storn, R., Price, K.: Differential evolution—a simple and efficient heuristic for global optimization over continuous spaces. *J. Glob. Optim.* **11**(4), 341–359 (1997)
2. Lakshminarasimman, L., Subramanian, S.: Short-term scheduling of hydrothermal power system with cascaded reservoirs by using modified differential evolution. *IEE Proceedings-Generation, Transmission and Distribution* **153**(6), 693–700 (2006)
3. Reddy, M.J., Kumar, D.N.: Multiobjective differential evolution with application to reservoir system optimization. *J. Comput. Civil Eng.* **21**(2), 136–146 (2007)
4. Vasani, A., Raju, K.S.: Application of differential evolution for irrigation planning: an Indian case study. *Water Resour. Manag.* **21**(8), 1393 (2007)
5. Reddy, M.J., Kumar, D.N.: Evolving strategies for crop planning and operation of irrigation reservoir system using multi-objective differential evolution. *Irrig. Sci.* **26**(2), 177–190 (2008)

6. Mandal, K.K., Chakraborty, N.: Short-term combined economic emission scheduling of hydrothermal power systems with cascaded reservoirs using differential evolution. *Energy Convers. Manag.* **50**(1), 97–104 (2009)
7. Qin, H., et al.: Multi-objective cultured differential evolution for generating optimal trade-offs in reservoir flood control operation. *Water Resour. Manag.* **24**(11), 2611–2632 (2010)
8. Suribabu, C.R.: Differential evolution algorithm for optimal design of water distribution networks. *J. Hydroinform.* **12**(1), 66–82 (2010)
9. Adeyemo, J., Otieno, F.: Differential evolution algorithm for solving multi-objective crop planning model. *Agric. Water Manag.* **97**(6), 848–856 (2010)
10. Vasan, A., Simonovic, S.P.: Optimization of water distribution network design using differential evolution. *J. Water Resour. Plan. Manag.* **136**(2), 279–287 (2010)
11. Regulwar, D.G., Choudhari, S.A., Raj, P.A.: Differential evolution algorithm with application to optimal operation of multipurpose reservoir. *J. Water Resour. Prot.* **2**(06), 560 (2010)
12. Adeyemo, J.A.: Reservoir operation using multi-objective evolutionary algorithms—a review. *Asian J. Sci. Res.* **4**(1), 16–27 (2011)
13. Fallah-Mehdipour, E., Bozorg Haddad, O., Mariño, M.A.: Extraction of multicrop planning rules in a reservoir system: application of evolutionary algorithms. *J. Irrig. Drain. Eng.* **139**(6), 490–498 (2012)
14. Ahmad, A., et al.: Reservoir optimization in water resources: a review. *Water Resour. Manag.* **28**(11), 3391–3405 (2014)
15. Schardong, A., Simonovic, S.P.: Coupled self-adaptive multiobjective differential evolution and network flow algorithm approach for optimal reservoir operation. *J. Water Resour. Plan. Manag.* **141**(10), 04015015 (2015)
16. Ochoa, P., Castillo, O., Soria, J.: Fuzzy differential evolution method with dynamic parameter adaptation using type-2 fuzzy logic. In: 2016 IEEE 8th International Conference on Intelligent Systems (IS). IEEE (2016)
17. Ochoa, P., Castillo, O., Soria, J.: A new approach for dynamic mutation parameter in the differential evolution algorithm using fuzzy logic. In: North American Fuzzy Information Processing Society Annual Conference. Springer, Cham (2017)
18. Ochoa, P., Castillo, O., Soria, J.: Differential evolution using fuzzy logic and a comparative study with other metaheuristics. In: Nature-Inspired Design of Hybrid Intelligent Systems, pp. 257–268. Springer International Publishing, Cham (2017)