

Application of Genetic Algorithm for Reservoir Operation: A Case Study of Karjan Reservoir Project

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ABSTRACT:The major issue in water resources planning and management is how to find out the optimized releases for determining the operating policy of reservoirs. Genetic Algorithms (GAs) are adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and genetics. As such they represent an intelligent exploitation of a random search used to solve optimization problems. Although randomised, GAs are by no means random, instead they exploit historical information to direct the search into the region of better performance within the search space. This study is carried out to develop a policy for optimizing the releases of water for the irrigation purpose of Karjan Reservoir Project. The years considered are from 2008-09 to 2011-12. Monthly releases for irrigation from the reservoir and initial storages in reservoir at beginning of the month are the decision variables. For this Optimization, the constraints considered are the bounds for the releases and reservoir capacity. Results show that in the year of 2008-09, total 19.89 % of water is saved than the actual release. For 2009-10, 8.439 % of water is saved than the actual release. In the year 2010-11, 2.62% more water is needed to be released to satisfy the downstream irrigation demand. In the year 2011-12, 11.77% water can be saved than the actual release using Genetic Algorithm. The study reveals that using Genetic Algorithm, irrigation demands are satisfied, monthly releases for irrigation are optimized and water is saved.

KEYWORDS: Genetic algorithm, Optimization, Reservoir .

I. INTRODUCTION

Among the various elements of water resources planning and management, Reservoir Operation is an important element. Reservoir Operation contains several control variables. Operation of reservoir is done to meet the different objectives, such as hydropower generation flood control and allocation of water to different users. For guiding a sequence of releases to meet a large number of demands from stakeholders with these different objectives, operation strategies are defined by the control variables. Practically, it is very difficult to fulfill all the demands which are due to conflicting and unequal objectives in the Reservoir Operation. Therefore, it is necessary to find out some balanced solutions between these conflicting objectives. One of the solutions of these conflicting objectives is optimized reservoir operation.

Genetic algorithm (GA) is a heuristic technique based on a population. It mimics the biological reproduction system. It is used to solve search and optimization problems. The operation of GA is based on the theory of survival of the fittest in which fittest survive and the weakest die off. To form a robust search mechanism, they combine the concept of the survival of fittest with genetic operators extracted from nature. In determining the reservoir operation policies, use of Genetic algorithm (GAs) is receiving significant attention from water resources engineers. For various complex reservoir problems, large number of works has been reported on the application of GA. Jothiprakash and Ganesan[1] developed a Genetic Algorithm model and applied to Pechiparai reservoir in Tamil Nadu, India to derive the optimal

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operational strategies. The objective function was set to minimize the annual sum of squared deviation from desired irrigation release and desired storage volume. The decision variables were release for irrigation and other demands (industrial and municipal demands), from the reservoir. Hence based on that case study it was concluded that GA model could perform better if applied in real world operation of the reservoir. Kumar[2] presented in paper, a genetic algorithm GA model for obtaining an optimal operating policy and optimal crop water allocations from an irrigation reservoir. The model is applied to the Malaprabha single-purpose irrigation reservoir in Karnataka State, India. The optimal operating policy Optimized using the GA is similar to that Optimized by linear programming. The model integrates the reservoir releases with the consequent soil moisture at the root level for each crop and for each period. The model was applied to an existing single purpose reservoir in Karnataka State, India. In rabi season AET Optimized is almost equal to PET indicating that optimal allocations were Optimized from this model. It is observed that AET values Optimized by GA and LP compared well. The operating policies evolved by the study can be adopted in the field, for optimizing the utilization of the existing resources to obtain maximum benefits. Kangrang [3] stated that rule curves of reservoir are necessary guides for long term reservoir operation. The KaengLoeng Chan reservoir was considered to improve their rule curves. The calculations are based on a simulation model using Genetic Algorithms and the water balance equation (GAs-WB) with the objective function of a minimal average annual water shortage. The results have shown that the pattern of the Optimized rule curves similar to the existing rule curve. The Optimized rule curves were used to simulate the Kaeng Loeng Chan system for evaluating the situation of water deficit and flood release in long term operation considering synthetic inflow as well as increased inflow of 10%, 20% and 30%. The results have indicated that the situations of water shortage and excess release of the new rule curves are smaller than their existing rule curves. Noori [4] presented a Genetic Algorithm model for optimal operation of a multi-reservoir and multi-objective water resource system in GhezelOzan watershed for hydropower generation and flood control is developed. The system is made of two reservoirs in series on the GhezelOzan's river. This model is used for optimal reservoir operation, allocation of water among different power plants and keeping a part of storage volume to control the probable floods using a definite combination of decision variables. Mathurand Nikam [6] proposed that in reservoir operation, appropriate methodology for deriving reservoir operating rules should be selected and operating rules should then be formulated. In the present study Genetic Algorithm (GA) has been used to optimize the operation of existing multipurpose reservoir in India, and to derive reservoir operating rules for optimal reservoir operations. The sensitivity analysis of GA model applied to this particular reservoir suggests optimal size of population to be used 250 and probability of crossover of 0.75, to find optimal releases for Upper Wardha reservoir. The model resulted in an irrigation releases equal to irrigation demand. Hence based on the present case study it can be concluded that GA model has the capability to perform efficiently, if applied in real world operation of the reservoir.

II. STUDY AREA

The area selected for the present study is the catchment area of the Karjan dam. The Karjan Reservoir Project is situated near Jitgadh village of Nanded Taluka, Dist. Narmada of Gujarat State across river Karjan, a left bank tributary of river Narmada and having its confluence downstream of Sardar Sarovar Project. The Karjan project basin lies on the western coast of Indian continent, between $73^{\circ}5'$ and $73^{\circ}40'$ longitude east and $21^{\circ}30'$ & $22^{\circ}0'$ latitude north. The elevation of the project area varies between 18m to 120m above mean sea level. The catchment area up to Dam site at Jitgadh is 1403 Sq.Km. out of which 31.08 Sq.km. lies in Maharashtra and remaining 1372.70 Sq.km. is in the Gujarat State. The project envisages irrigation in CCA of 13690 (Right), 42510 (Left) ha area through its left and right bank canal system. The dead storage and Gross storage for the Karjan reservoir is 22.63 MM^3 and 545.394 MM^3 respectively. The canal carrying capacity for the project is $10.13 \text{ m}^3/\text{sec}$ for R.B.M.C. and $28.30 \text{ m}^3/\text{sec}$ for L.B.M.C. The benefited area from the Karjan project is spread in the Nandod, Jhaghadia, Valia and Ankleshwar Talukas of Bharuch district in Gujarat.

III. IRRIGATION DEMAND

Irrigation Demand is a very important parameter considered for the present study. In this study, irrigation demand is determined considering crop area and crop water requirement for that particular crop on the monthly basis. The canal

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efficiency for this project is considered as 50%. So in the final calculated irrigation demand for any particular month, this canal efficiency is added and then it is considered as the final Irrigation Demand for that particular month.

IV. METHODOLOGY

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

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

Where,

(1)

R_t = monthly irrigation release for the month 't'.

D_t = monthly downstream irrigation demand for the month 't'.

I_t = monthly inflow during the period 't',

S_t = initial storage in the beginning of month 't'.

S_{t+1} = final storage at the end of month 't', and

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

The constraints and bounds for the above fitness function of GA model are as following,

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,

$$R_t \leq D_t, (2)$$

t = 1 to 12

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

$$S_t \leq S_{max} (3)$$

t = 1 to 12

Where,

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

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

V. RESULTS AND DISCUSSION

The data used for calculation of irrigation demand are cropping pattern and crop water requirement for all the crops in the command area on monthly basis.

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TABLE 1: IRRIGATION DEMAND CALCULATED FOR YEARS 2008-09 TO 2011-12 IN MCM

Year	2008-09	2009-10	2010-11	2011-12
Months	IRRIGATION DEMAND, MCM			
July	12.20	10.77	17.07	18.15
August	12.29	10.91	17.21	18.40
September	2.41	2.66	2.63	3.12
October	10.80	17.44	18.17	17.55
November	12.09	18.66	18.68	18.02
December	12.40	18.68	18.43	17.43
January	15.44	25.32	25.56	23.52
February	17.47	27.35	27.97	25.50
March	18.34	26.45	28.90	26.28
April	19.58	27.42	30.02	27.34
May	20.20	27.63	30.34	27.67
June	13.07	21.09	23.29	21.15

Table 1 shows irrigation demand calculated for the years 2008-09 to 2011-12. All the irrigation demand shown in table 1 is in MCM (Millions Cubic Meter) unit. Irrigation demands of all the years considered is calculated on monthly basis. The data used for the application of Genetic algorithm (GA) to the above formulated model are inflow, demand, actual release, evaporation and storage in MCM. The monthly inflows in to the reservoir system and monthly irrigation demands for all the months from year 2008-09 to 2011-12, are the important input variables in present GA model study. To compute the quantity of water that should be released to meet the monthly irrigation demand is the main objective of the study. The parameters considered in GA are population size of 5, probability of crossover of 0.80, number of generations from 100 to 500 and selection function Roulette wheel selection. The following results are generated which gives the releases by GA and that we consider as optimized releases for year 2008-09 to 2011-12.

TABLE 2: DEMAND, ACTUAL RELEASE AND OPTIMIZED RELEASE BY GA FOR THE YEAR 2008-09

Year	Month	Demand MCM	Actual Release MCM	Optimized Release MCM
2008-09	July	12.20	0.72	15.01
	August	12.29	0.00	19.99
	September	2.41	0.00	6.39
	October	10.80	9.74	15.61
	November	12.09	41.14	14.13
	December	12.40	15.29	18.43
	January	15.44	20.65	17.44
	February	17.47	24.24	20.85
	March	18.34	27.67	21.89
	April	19.58	38.38	21.53
	May	20.20	45.63	22.85
	June	13.07	39.29	16.36

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Table 2 shows the values of the demand, actual release and optimized release by applying genetic algorithm for each of the month for the year 2008-09. From the values of the Releases by GA, it can be shown that for all the months, the demands are completely satisfied. Table 2 is represented graphically in Fig. 1.

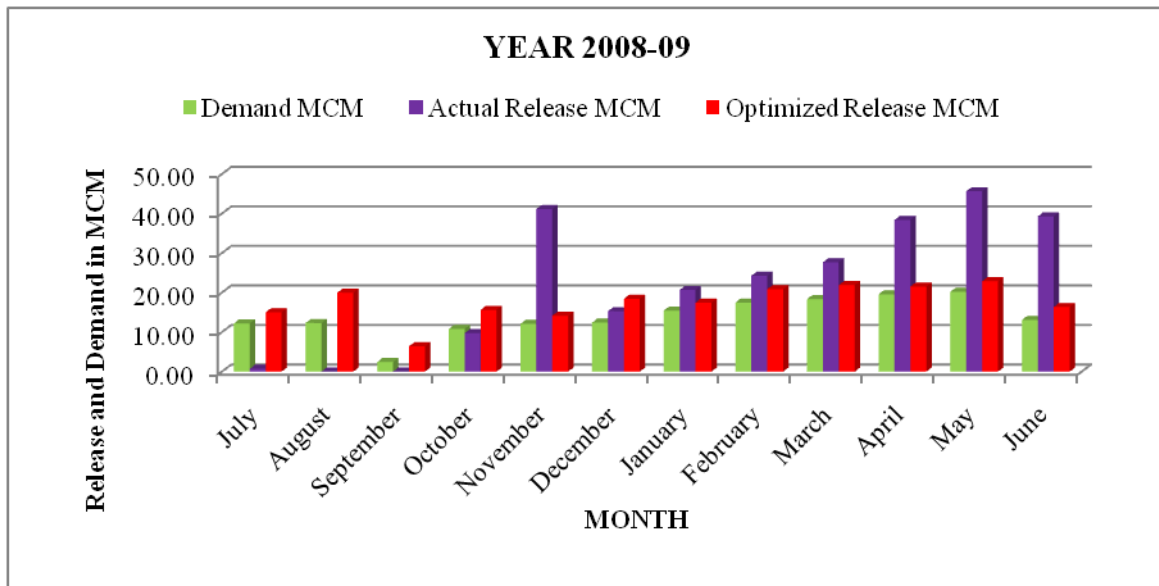


Fig.1 Demand, Actual Release and Optimized release for Year 2008-09

Fig.1 shows the demand, actual release, release optimized by applying genetic algorithm for all the months for the year 2008-09. From Fig.1, it is observed that in the month of November and January to June, the releases optimized by GA is less than the actual release and in the other months, the release optimized by GA is more than the actual release but care is taken to satisfy the demands.

TABLE 3: AMOUNT AND PERCENTAGE OF WATER SAVED IN MCM FOR THE YEAR 2008-09

Month	Water Saved (MCM)	Percentage of Water Saved %
July	*	*
August	*	*
September	*	*
October	*	*
November	27.011	65.66
December	*	*
January	3.206	15.53
February	3.389	13.98
March	5.783	20.90
April	16.849	43.90
May	22.776	49.91
June	22.935	58.37

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Table 3 shows the amount of water and percentage of water that can be saved than the actual release using GA for the year 2008-09. From the table 3, it can be seen that in the month of November, January, February, March, April, May and June, water saved is 65.66, 15.53, 13.98, 20.90, 43.90, 49.91 and 58.37 MCM respectively. The asterisk (*) is used to show that the release optimized by GA is more than the actual release, so water is not saved, but instead care is taken to fulfill the demands. From the Table, it can be seen that in the month of November 65.66 %, for January 15.53 %, for February 13.98 %, for March 20.90 %, for April 43.90 %, for May 49.91 % and for June 58.37 % of water is saved than the actual release.

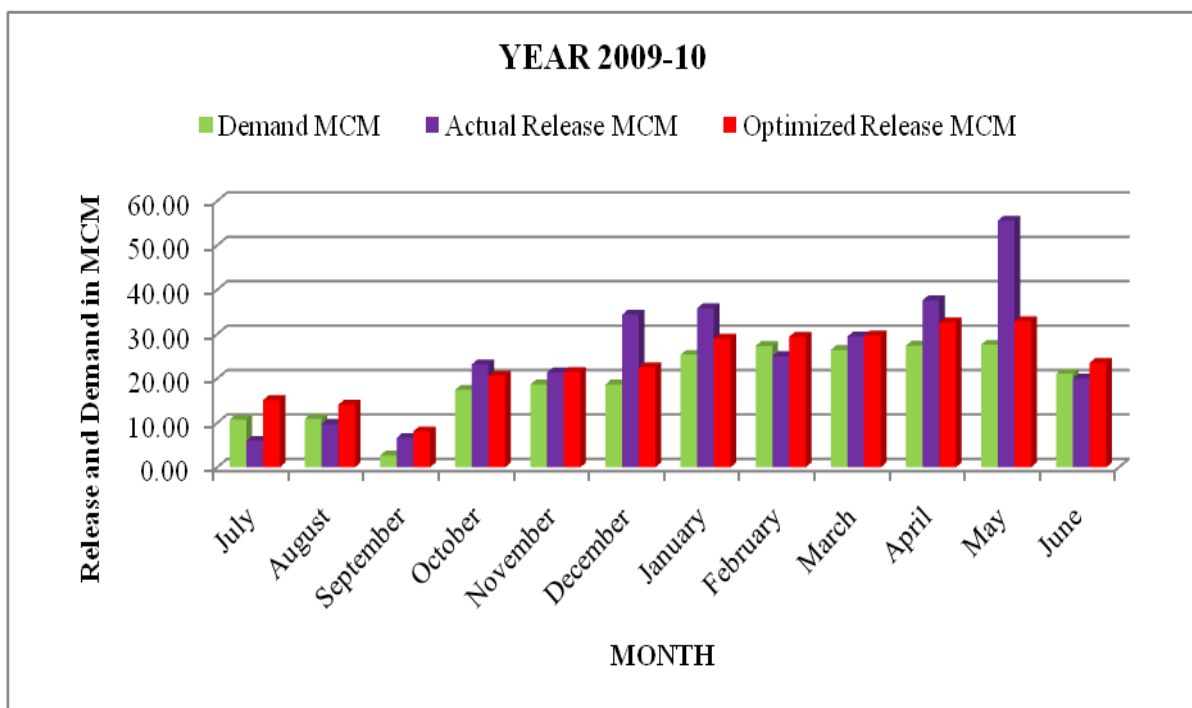


Fig.2 Demand, Actual Release and Optimized release for Year 2009-10

In the same way, optimized releases for all the months of the other years are found out by using genetic algorithm. From the values of the releases by GA, it can be shown that for all the months, the demands are completely satisfied. Demand, Actual releases and optimized releases are represented graphically in Fig. 2 for all the months of year 2009-10.

Fig.2 shows the Demand, Actual release and release optimized by applying genetic algorithm for all the month for the year 2009-10. From Fig.2, it is observed that in the month of October, December, January, April and May, the release optimized by GA is less than the actual release and in other months the release optimized by GA is more than the actual release, but care is taken to satisfy the demands.

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TABLE 4: AMOUNT AND PERCENTAGE OF WATER SAVED IN MCM FOR THE YEAR 2009-10

Month	Water Saved (MCM)	Percentage of Water Saved %
July	*	*
August	*	*
September	*	*
October	2.580	11.12
November	*	*
December	11.817	34.36
January	6.846	19.09
February	*	*
March	*	*
April	4.985	13.25
May	22.676	40.81
June	*	*

Table 4 shows the amount of water and percentage of water that can be saved than the actual release using GA for the year 2009-10. From the table 4, it can be seen that in the month of October, December, January, April and May, water saved is 11.12, 34.36, 19.09, 13.25 and 40.81 MCM respectively. The asterisk (*) is used to show that the release optimized by GA is more than the actual release, so water is not saved, but instead care is taken to fulfill the demands. The results show that, for October 11.12 %, for December 34.36 %, for January 19.09 %, for April 13.25 % and for May 40.81 % of water is saved than the actual release.

For all the months of year 2010-11, Demand, Actual releases and optimized releases are represented graphically in Fig. 3.

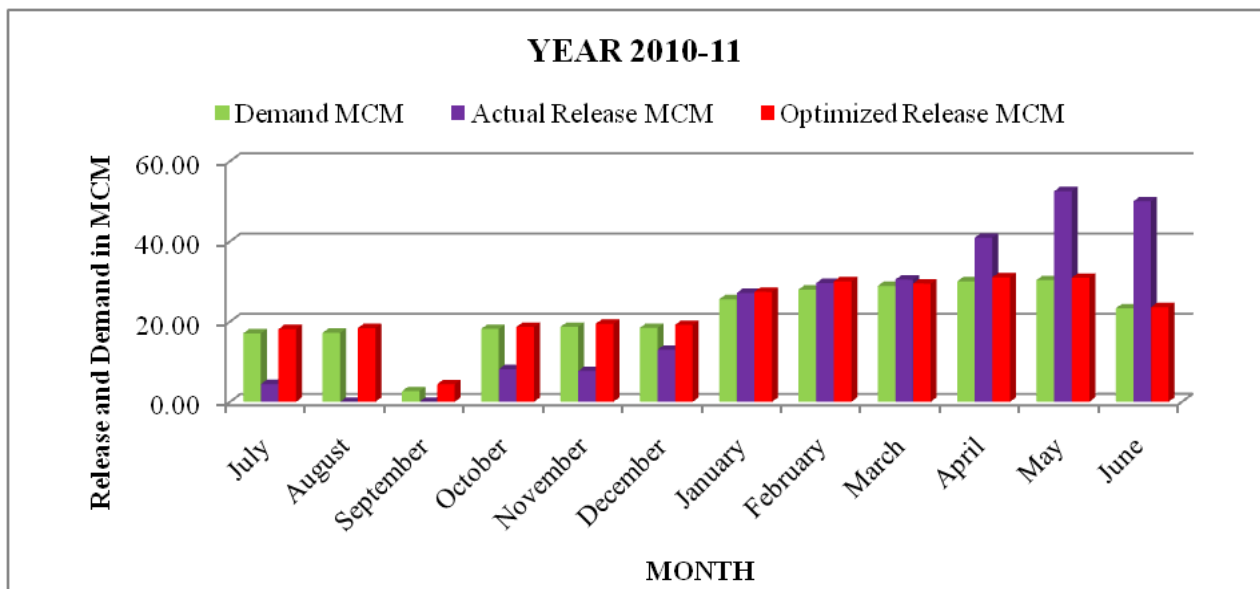


Fig.3 Demand, Actual Release and Optimized release for Year 2010-11

Fig.3 shows the demand, actual release, release optimized by applying genetic algorithm for all the month for the year 2010-11. From Fig.3, it is observed that in the month of March to June, the releases optimized by GA is less than the actual release and also care is taken to satisfy the demands.

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TABLE 5: AMOUNT AND PERCENTAGE OF WATER SAVED IN MCM FOR THE YEAR 2010-11

Month	Water Saved (MCM)	Percentage of Water Saved %
July	*	*
August	*	*
September	*	*
October	*	*
November	*	*
December	*	*
January	*	*
February	*	*
March	0.993	3.26
April	9.857	24.10
May	21.577	41.10
June	26.407	52.81

Table 5 shows the amount of water and percentage of water that can be saved than the actual release using GA for the year 2010-11. From the table 5, it can be seen that in the months of March, April, May and June the amount of water saved is 0.993, 9.857, 21.577 and 26.407 MCM respectively. While in the other months the actual release is greater than the Optimized release. It shows that water is not saved in these months but care is taken to completely satisfy the demand. The results show that, for March 3.26 %, for April 24.10 %, for May 41.10 % and for June 52.81 % of water is saved than the actual release.

For all the months of year 2010-11, Demand, Actual releases and optimized releases are represented graphically in Fig.4.

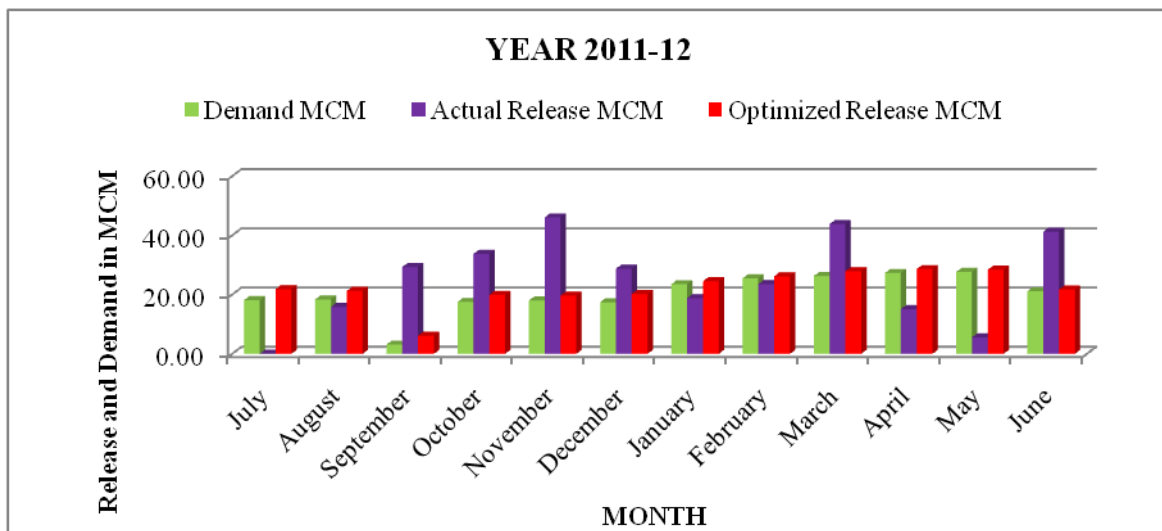


Fig.4 Demand, Actual Release and Optimized release for Year 2011-12

Fig.4 shows the Demand, Actual release, release optimized by applying genetic algorithm for all the month for the year 2011-12. From Fig.4, it is observed that in the month of September to December, March and June, the releases optimized by GA are less than the actual releases and also care is taken to satisfy the demands. The amount of water and percentage of water that can be saved than the actual release is shown in Table 6.

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TABLE 6: AMOUNT AND PERCENTAGE OF WATER SAVED IN MCM FOR THE YEAR 2011-12

Month	Water Saved (MCM)	Percentage of Water Saved %
July	*	*
August	*	*
September	23.219	79.14
October	13.841	40.98
November	26.444	57.37
December	8.569	29.80
January	*	*
February	*	*
March	15.913	36.29
April	*	*
May	*	*
June	19.559	47.37

Table 6 shows the amount of water and percentage of water that can be saved than the actual release using GA for the year 2011-12. From the table 6, it can be seen that in the months of September, October, November, December, March and June the amount of water saved is 79.14, 40.98, 57.37, 29.80, 36.29 and 47.37 MCM respectively. While in the other months the actual release is greater than the Optimized release. It shows that water is not saved in these months but care is taken to completely satisfy the demand. The results show that in the month of September 79.14%, in October 40.98%, in November 57.37%, in December 29.80%, in March 36.29% and in June 47.37% of water is saved than the actual release.

VI. CONCLUSION

The releases developed by Genetic algorithm satisfy completely the irrigation demands for all months each year from year 2008-09 to 2011-12. Overall in the year of 2008-09, total 19.89%, for 2009-10, 8.439 % of water is saved than the actual release. Now in the year 2010-11, 2.62% more water is needed to be released than the actual releases to satisfy the downstream irrigation demand. In the year 2011-12, 11.77% water can be saved than the actual release using Genetic Algorithm. Thus, GA model can completely satisfy downstream irrigation demands for all the years considered for the present study and releases are minimized for three out of four years which leads to considerable amount of saving in water, if applied to the Karjan reservoir project in Gujarat state, India.

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