*J. Indian Water Resour. Soc., Vol. 38, No. 4,Oct., 2018*

# OPTIMAL WATER UTILIZATION OF RESERVOIR FOR IRRIGATION BY GENETIC ALGORITHM TECHNIQUE

**Abhay Kumar Jha[1], Sandeep Narulkar[2] and Saleem Akhtar[3]**

## ABSTRACT

*Irrigation reservoirs have an objective of maximizing the crop yield by optimizing the water supply. Use of conventional optimization techniques as well as meta-heuristic techniques is common to solve the optimization problems. Genetic Algorithm is one of the meta-heuristic evolutionary algorithms which is applied to solve the problem of reservoir operation for irrigation in the present study. The main objective is to maximize the crop yields in a multi-crop scenario. Two formulations are solved, one is additive function and other is product function. The developed model is applied to a reservoir in the state of Madhya Pradesh. The reservoir is filled in Monsoon and the storage is used for irrigating crops in Rabi Season. The reservoir gets filled up to different levels of storage each year. The optimization problem has been solved for 6 discrete storage levels. The problem is solved on GA Solver on MATLAB Platform. There are no deficits up to 5$^{th}$ level of storage but a deficit is encountered at 6$^{th}$ level of storage. The additive formulation results into maximization of relative yield of wheat whereas the multiplicative model maximizes relative yield of other crops. The results illustrate that multiplicative model yields better relative yield values.*

**Keywords:** *Water resources system, Optimal Operation, Evolutionary Algorithms, Crop yield, Genetic Algorithm.*

## INTRODUCTION

Irrigated agriculture consumes maximum fresh water and is perhaps the most mismanaged water use sector worldwide. Efficient use of water for irrigation is critical to social and economic sustainability of a country. Efficient water use is to produce maximum yield per unit of water supplied. Enhancement of crop production per unit of water is the main aim of irrigation water management. This is the crux of social, economic and environmental sustainability of India. The rainfall vis-a-vis the runoff in the rivers is quite uncertain in India and the runoff in most of the rivers in seasonal. Further there is a gap between the demand and supply. Thus, reservoirs are necessary on the rivers to squeeze the gap between demand and supply.

Many reservoirs have been planned and commissioned in India. These reservoirs serve multiple purposes viz. Municipal and Industrial Water Supply, Irrigation, hydropower generation etc. But most of the reservoirs are exclusively created for irrigation. Reservoirs are the core components of water management systems but require huge investments of resources in terms of money, land and environment. Benefits are accrued only if the reservoir is planned and operated in an optimal way.

Optimal operation of a planned reservoir is important. The reservoirs operated for irrigation have a special objective of maximizing the crop yield by supplying optimal water over space and time. Use of conventional optimization techniques has been in vogue since decades. The most common mathematical optimization techniques are Linear Programming, Dynamic Programming and Non Linear Programming. Best reviews for development and application of these techniques are available in the works of Yeh (1985), Wurbs (1991), Mujumdar and Narulkar (1993), Labadie (2004) and Rani and Moreira (2010) indicating development and applications of these techniques to reservoir planning and operation.

Past three decades have witnessed the advent of the research on Evolutionary Algorithms mimicking the genetics or flocking behavior of the animals. Lot of research is getting published and the techniques have been reviewed by Adeyemo (2011), Ahmad et al. (2014) and Neboh et al. (2015). The major technique in this category that has been applied on the reservoir operation and management are Genetic Algorithms (GA). The textbook written by Goldberg (2015) compiles all the features of the GA. GA is a search heuristic that imitates the process of natural evolution such as inheritance, mutation, selection, and crossover. Many researchers have contributed to the enhancement of the GA especially by combining it with other method (hybrid) and by comparing the performance (Ahmad et al., 1989). East and Hall (1994) first applied GAs to a four-reservoir problem in their paper. Nicklow et al. (2010) have presented a state of the art paper on GA and its extensions applied to the water resources management problems. The problems of reservoir systems have been dealt by Wardlaw and Sharif (1999), Sharif and Wardlaw (2000), Tospornsampan et al (2005), Ahmed and Sarma (2005). Reddy and Kumar (2006), Jyothiprakash and Ganeshan (2006), Chen et al. (2007), Azamathulla et al. (2008), Mathur and Nikam (2009), Scola et al. (2010), Anand et al. (2018) and many more. The other techniques that are applied to the reservoir operation problems are Differential Evaluation (DE) (Reddy and Kumar (2005), Arunkumar and Jothiprakash (2011)), Particle Swarm Optimization (PSO) (Reddy and Kumar (2007), Yang (2001)), Ant Colony Optimization (ACO) (Dariane, and

1. *Research Scholar, UIT, RGPV, Bhopal-462023, abhaykumarjha0907@gmail.com*
2. *Professor, SGSITS, Indore-452003, snarulkar@gmail.com*
3. *Professor, UIT, RGPV, Bhopal-462023, sargpv@gmail,com*

*Manuscript No. 1509*

Moradi (2008)), Honey-Bee Mating Optimization (HBMO) (Barros et al. (2008)). Many new evolutionary techniques have also been discussed in literature. Present study is based on a GA Model to develop a release policy that distributes the water stored in the reservoir optimally in various fortnights amongst various crops. The case study is chosen as Samrat Ashok Sagar Reservoir on River Halali in Districts Vidisha and Raisen of the state of Madhya Pradesh (M. P.). The command area served by the reservoir is also termed as bowl of wheat. It produces best quality Sharbati Wheat that is quite famous in India and abroad.

## METHODOLOGY

The GA technique is adopted for optimization of the water management problem in the present study. The specific objective of the study is to maximize the yield and to allocate water in a multi-crop and multi-period scenario. The problem is solved in three stages; First stage is the data collection process of cropping pattern in the study area along with the meteorological information. Second stage is fortnightly crop water requirement are calculated by using the Penman Monteith method (Allen et al. (1998)) and the relative yield ratios are evaluated from Doorenbos and Kassam, (1979) and other publications. Third stage is data preparation and application to the models formulated in the following section and solving both the models to get results.

### Demand Computation

The estimation of the reference crop evapotranspiration is done through CROPWAT-8.0 Software available as an open access freeware. The Reference evapotranspiration (RET) is the evapotranspiration rate from a reference surface with hypothetical grass crop sown without any shortage of water and is denoted as $ET_{o.}$ It uses many inputs related to climatic conditions, geographic information, soil characteristics, and water quality at the region of interest. In order to relate automatically the different existing formulae using the different inputs in order to generate water requirements and maximum yield for each crop of interest the software has sufficient capability. The software assumes that all other input factors to crop yield (such as pesticides, know-how, seeds etc.) are kept at their optimal levels. Following lines discuss the details of the software. The equation used is the FAO Penman-Monteith Equation. The reference evapotranspiration value in $i^{th}$ season ($ET_o$) is calculated as per the Equation 1. (1998)

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \Upsilon\,\frac{900}{T+273}\,u_2\,(e_s - e_a)}{\Delta + \Upsilon\,(1 + 0.34\,u_2\,)} \qquad (1)$$

Where: $ET_{o\,=}$ the reference evapotranspiration [mm / day], $R_n$ = net radiation received at the crop surface [MJ $m^{-2}$ $day^{-1}$], G = the soil heat flux density [MJ $m^{-2}$ $day^{-1}$], T = the mean daily air temperature at 2 m height [°C], $u^2$ = wind speed at 2 m height [m $s^{-1}$], $e_s$ = saturation vapour pressure [kPa] at T [°C], $e_a$ = actual vapour pressure [kPa], Δ = slope of vapour pressure curve [kPa $°C^{-1}$], γ = the psychrometric constant [kPa $°C^{-1}$]. For the various crops sown in an area the crop evapotranspiration is required to assess the water requirement of individual crops in different seasons. The reference evapotranspiration ($ET_o^i$) values computed for different fortnights i were multiplied by the crop coefficient ($k_c^i$) to get the crop evapotranspiration ($ET_c^i$ ) (Equation 2)

$$ET_c^i = k_c^i * \text{ETo}^i \qquad (2)$$

### Model Development

The formulation of the optimization of the reservoir operation problem for the Samrat Ashok Sagar Reservoir is discussed. The objective function and various constraints are summarized below.

### Objective Function

In the present study, the two different problems with different objective functions were solved.

### Objective Function 1 (Additive Model)

The objective function of the GA model for the first problem is minimizing the sum of the squared deviation of irrigation demand deficit along with squared deviation of mass balance equation. (Equation 1) This objective function is termed as additive function. This kind of objective function has been used by many researchers in the past (Reddy and Kumar (2006), Azamathulla et al. (2008), Mathur and Nikam (2009), Reddy and Kumar (2007)). In the works of Reddy and Kumar (2006) and Mathur and Nikam (2009) the objective function was not weighed by the crop sensitivity factor to the water deficit in different growth stages. Present objective function is a weighted sum of the squared deficit between the releases and demand of each crop in each season. (Equation 3)

$$\boldsymbol{min\, f(x)} = \sum_{nc=1}^{NC}\sum_{t=1}^{N} ky_t^{nc}\left(\boldsymbol{R_{t,nc}} - \boldsymbol{D_{t,nc}}\right)^2$$

$$+\sum_{t=1}^{N}\left(\mathbf{S}_{\mathbf{t}}(\mathbf{1}-\mathbf{B}*\mathbf{e_t}) - \mathbf{S}_{\mathbf{t+1}}(\mathbf{1}+\mathbf{B}*\mathbf{e_t}) + \mathbf{I_t} - \right.$$

**nc=1NCRt,nc−Ao∗et2** (3)

$R_{t,nc}$ = release in the period *t = 1, 2..., N* for crop *nc = 1, 2, ..., NC* (MCM), $D_{t,nc}$ = demand to sustain the crop *nc = 1,2,..., NC* in the period *t=1, 2..., T* (MCM), $ky_t^{nc}$ = yield response factor for time period *t= 1, 2..., N* of crop *nc = 1, 2..., NC*, $S_t$ = Storage at time period *t= 1, 2..., N* (MCM), $S_{t+1}$= Storage at time period *t+1* (MCM), $I_t$ = Inflow at time period *t= 1, 2..., N* (MCM), $A_o$ and *B* = Regression constant correlating surface area (Ha) and storage value, $e_t$= Rate of evaporation at each fortnight in (mm)

### Objective Function 2 (Multiplicative Model)

The additive model discussed in previous paragraph has a limitation that it works in local time and the optimization model does not have the effect of the deficits occurred in other time periods whereas the multiplicative model (Eq. 4) is more realistic and takes in to account the effect of deficits to the other seasons.

$$\boldsymbol{min\, f(x)} = \sum_{nc=1}^{NC} \prod_{t=1}^{N} ky_t^{nc}\left(\boldsymbol{R_{t,nc}} - \boldsymbol{D_{t,nc}}\right)^2 + \sum_{t=1}^{N}\Big(\mathbf{S}_{\mathbf{t}}(\mathbf{1} - \mathbf{B} * \mathbf{e_t}) - \mathbf{S}_{\mathbf{t+1}}(\mathbf{1} + \mathbf{B} * \mathbf{e_t}) + \mathbf{I_t} - \sum_{nc=1}^{NC} \mathbf{R_{t,nc}} \_ \;\mathbf{Ao * et2} \qquad (4)$$

### Irrigation Demand Constraints

The releases for irrigation should be more than or equal to zero to sustain the crops and also at the same time this should not exceed the maximum irrigation demand to produce the targeted yield

$$0 \le R_{t,nc} \le D_{t,nc} \qquad (5)$$

### Reservoir Storage – Capacity Constraints

The reservoir storage in each fortnight should not be less than the dead storage, and should not be more than the live storage of the reservoir

$$S_{min} \le S_t \le S_{max} \qquad (6)$$

On the basis of the models discussed in the foregoing text reservoir operation analysis for the data of Samrat Ashok Sagar Reservoir was carried out. The result reveals that the optimization approach can significantly improve the annual net benefits even in deficient storage situation. Under a multi-crop environment there is a competition for the available water whenever the water available is less than the irrigation demands. The reservoir operation component optimally releases water from the reservoir, whereas multi-crop water allocation component allocates water to different crops, by weighing the sensitivity of crop yield to moisture stress during different physiological growth stages of the plants. In the present study a single reservoir with multiple crop irrigation is considered for Rabi (dry weather) Season operation. The model formulation and methodologies of evaluation of various components of the study are presented in following paragraphs.

## DATA COLLECTION AND ANALYSIS

The data for the analysis was collected from various sources. The data regarding the cropping pattern and physical aspects of the reservoir were collected from the Central Water Commission (2006), visiting the dam site and various state level offices of M.P. Water Resources Departments in Bhopal and IMD website, Water Portal website etc. The Rabi Season irrigation is considered in the present problem and the cropping pattern is presented in Table 1. The monsoon season in India is uncertain and has a direct effect on the runoff to the reservoir which may lead to variation in filling levels of the reservoirs. In all 6 different levels of initial storage in the reservoir have been taken to analyze the problem in the present study. They are 226.9 (full storage), 204.2, 181.52, 158.53, 136.14 and 113.45 MCM. The total command area is 37419 Ha and the area to be covered by the reservoir system is 86.30% that is approximately 32292 Ha. The Crop calendar adopted for the present study is shown in Table 2. The adopted reference crop evapotranspiration values are shown in Table 3.

**Table .1: Cropping Patterns in the Case Study for Rabi Season**

| S. No. | CROP | % | AREA (Ha) |
|---|---|---|---|
| 1 | GRAM | 7 | 2400 |
| 2 | MOONG | 2 | 600 |
| 3 | VEGETABLE | 0.7 | 292 |
| 4 | WHEAT | 90 | 28900 |
| 5 | BARSEEM | 0.3 | 100 |
| | TOTAL | 100 | 32,292 |

**Table.2: The Crop Calendar Adopted**

| S. | CROP | TIME DURATION | DAYS |
|---|---|---|---|
| 1 | GRAM | 16 OCT - 28 FEB | 135 |
| 2 | MOONG | 15FEB – 15 APRIL | 60 |
| 3 | VEGETABLE | 1 NOV – 31 JAN | 90 |
| 4 | WHEAT | 16 NOV - 15 MAR | 120 |
| 5 | BARSEEM | 16 OCT - 15 FEB | 120 |

**Table.3: Reference Evapotranspiration Values**

| FORTNIGHT | TIME | ETo (mm) |
|---|---|---|
| 1 | 16-31 OCT | 53.98 |
| 2 | 1-15 NOV | 48.95 |
| 3 | 16- 31 NOV | 40.04 |
| 4 | 1-15 DEC | 40.00 |
| 5 | 16-31 DEC | 40.00 |
| 6 | 1-15 JAN | 40.04 |
| 7 | 16- 31 JAN | 49.00 |
| 8 | 1-15 FEB | 51.82 |
| 9 | 16- 28 FEB | 56.13 |
| 10 | 1-15 MAR | 85.72 |

### Computation of Demand of Water

The computation of season wise Reference Evapo-Transpiration ($ET_o$) values for the command area has been carried out using the CROPWAT 8.0 Software with the local climatic data for various growth seasons of Rabi Season (Dry Weather) crops. The $ET_o$ values were then converted into the crop Evapo-Transpiration ($ET_{c)}$ values for different crops by multiplying the $ET_o$ values with the crop evapotranspiration coefficients (Eq.2). Eventually the demands for the various seasons were computed using the net sown area and after the proper conversion and application of efficiency factors. The example results are shown for Gram crop is shown in Table 4. On the similar lines the demands for other crops have been computed.

**Table 4: Computation of Fortnightly Demand for Gram**

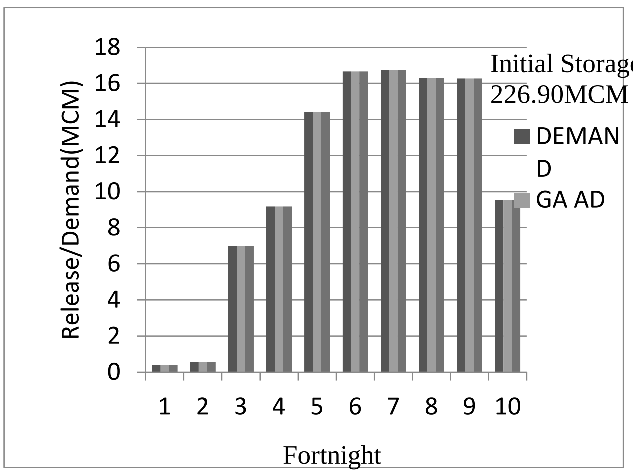
| SOWING DATE | 16-Oct | Crop | Gram | Area Sown | 2400 (Ha) | Computed Demand |
|---|---|---|---|---|---|---|
| DAYS | FORT NIGHT | $ET_o$ (mm) | Kc | Growth STAGE | $ET_C$=Kc* $ET_o$ (mm) | Million Cubic Meters (MCM) |
| 15 | 1 | 53.98 | 0.23 | ini | 12.4154 | 0.358 |
| 30 | 2 | 48.95 | 0.28 | devp | 13.706 | 0.395 |
| 45 | 3 | 40.04 | 0.69 | devp | 27.6276 | 0.796 |
| 60 | 4 | 40.00 | 1.02 | devp | 40.8 | 1.180 |
| 75 | 5 | 40.00 | 1.05 | devp | 42 | 1.210 |
| 90 | 6 | 40.04 | 1.04 | mid | 41.6416 | 1.199 |
| 105 | 7 | 49.00 | 0.89 | mid | 43.61 | 1.256 |
| 120 | 8 | 51.82 | 0.63 | mid | 32.6466 | 0.940 |
| 135 | 9 | 56.13 | 0.41 | end | 23.0133 | 0.663 |

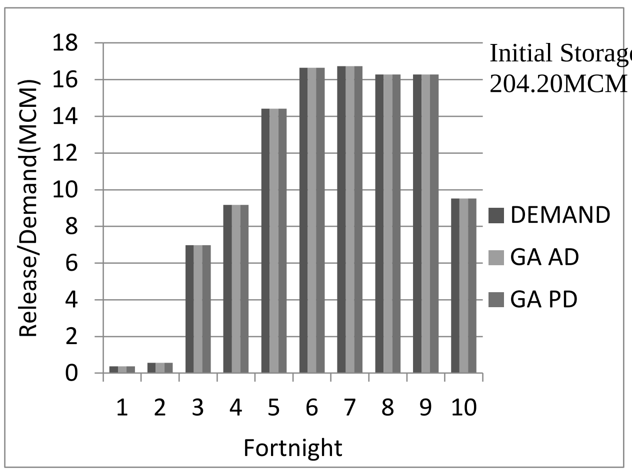
## RESULTS OF RELEASE AT VARIOUS INITIAL STORAGES

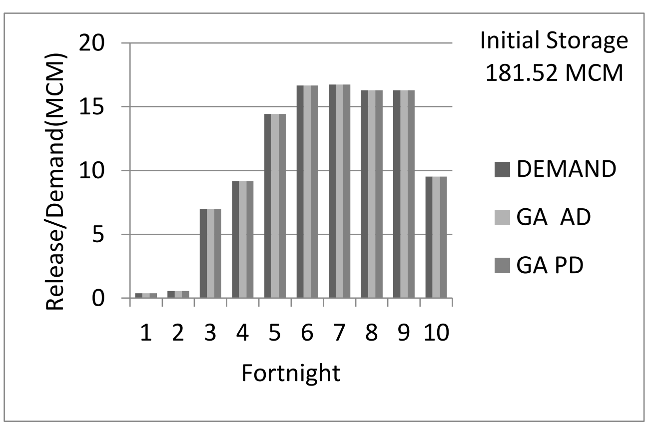
The Additive and Multiplicative Models were applied to the problem as per the formulation explained in the foregoing discussions (Equations 3 to 6). The actual demands, the computed releases from the Additive Model and the

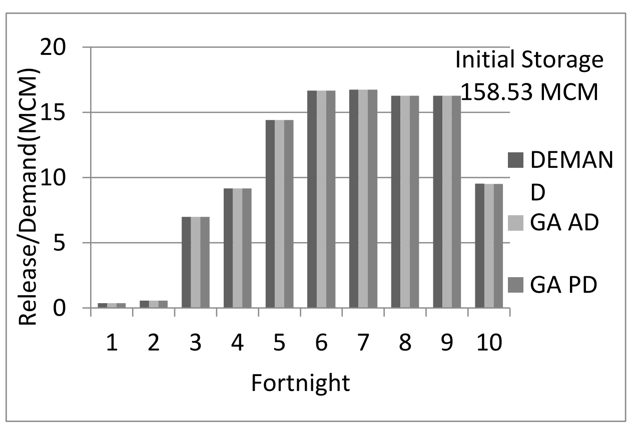
Multiplicative models in each fortnight for different levels of available initial reservoir storage values are calculated and presented in Figure 1 for the Gram crop.

In the similar fashion the releases were computed by both the models for different crops in the command area. The objective of the present study was to maximize the yield ratios for all the crops that is to maximize the production. The releases computed from the optimization model for different crops in different fortnights for various levels of



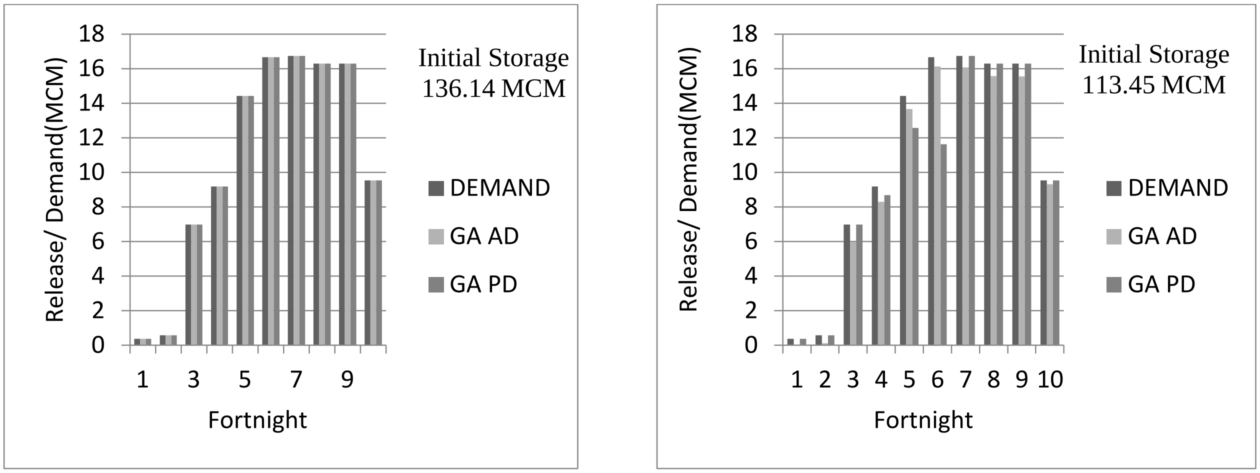



**Fig. 1: Fortnightly Demands and releases computed by both Models for Gram for all Initial Storage Values**

initial storage values in the reservoir are used to compute the depth of water supplied to the crop by dividing the total volume by the crop area and appropriate conversion factor. Then a soil moisture simulation model (Equation 7) was applied to each of the crops. The procedure comprises of solving three equations (Equations 7 to 9) at each time steps to solve for the Actual Evapo-transpiration and the soil moisture storage in the root zone of each crop in various time periods. The relative yield is computed as per the Equation 10.

$$SM_{t+1} * Z_{t+1} = SM_t * Z_t + R_t + X_t + S_o(Z_{t+1} - Z_t) - AET_t \qquad (7)$$

$$Z_t = Z_{max}\left[0.5 + 0.5\, sin\left\{3.03\left(\frac{t}{t_{max}}\right) - 1.47\right\}\right] \qquad (8)$$

$$AETt = \begin{cases} 0;\ SMt \le WPt \\ \frac{PETt\,(SM_t - WP)}{(1-p)(FC-WP)};\ WP < SM_t \le (1-p)\,(FC-WP) \\ PETt;\ SMt \ge (1-p)(FC-WP) \end{cases} \qquad (9)$$

$$R_t^*(X_t, AET_t) = 1 - ky_t^{nc}\left(1 - \frac{AET}{PET}\right)_t \qquad (10)$$

Where, $Z_t$ and $Z_{t+1}$ are root zone depths in the periods t and t+1 respectively, (cm), $R_t$ is the rainfall in the period t (mm), $X_t$ is the water depth allocated in period t (mm), $S_o$ is the initial soil moisture content in the extended root zone (mm/cm), $t_{max}$ is the time for the full development of root zone (days), $Z_{max}$ is the maximum possible depth of effective root zone, $ky_t^{nc}$ is the yield factor for period t of the crop nc, AET is the actual evapo-transpiration (mm) and $ET_c$ is the crop evapo-transpiration for the crop *nc* in time *t*, $SM_t$ and $SM_{t+1}$ are the soil moisture content in depth units per unit root depth in period t (mm/cm), FC = Field capacity (mm/cm), WP = Wilting point (mm/cm), p = Crop water depletion fraction. The results of final yields for various crops at different storage level using both the models have been presented in Table 5 and Figure 2.

**Table 5: Final yield for Gram by Addition function and Product function**

| | Storage | Relative Yield by Addition Function | Relative Yield by Product Function |
|---|---|---|---|
| Gram | 226.9 | 1.000 | 1.000 |
| | 204.21 | 1.000 | 1.000 |
| | 181.52 | 1.000 | 1.000 |
| | 158.83 | 1.000 | 1.000 |
| | 136.14 | 1.000 | 1.000 |
| | 113.45 | 0.992 | 0.998 |
| Barseem | 226.9 | 1.000 | 1.000 |
| | 204.21 | 1.000 | 1.000 |
| | 181.52 | 1.000 | 1.000 |
| | 158.83 | 1.000 | 1.000 |
| | 136.14 | 1.000 | 1.000 |
| | 113.45 | 0.927 | 0.991 |
| Moong | 226.9 | 1.000 | 1.000 |
| | 204.21 | 1.000 | 1.000 |
| | 181.52 | 1.000 | 1.000 |
| | 158.83 | 1.000 | 1.000 |
| | 136.14 | 1.000 | 1.000 |
| | 113.45 | 0.911 | 0.997 |
| Vegetable | 226.9 | 1.000 | 1.000 |
| | 204.21 | 1.000 | 1.000 |
| | 181.52 | 1.000 | 1.000 |
| | 158.83 | 1.000 | 1.000 |
| | 136.14 | 1.000 | 1.000 |
| | 113.45 | 0.935 | 0.987 |
| Wheat | 226.9 | 1.000 | 1.000 |
| | 204.21 | 1.000 | 1.000 |
| | 181.52 | 1.000 | 1.000 |
| | 158.83 | 1.000 | 1.000 |
| | 136.14 | 1.000 | 1.000 |
| | 113.45 | 1.000 | 0.993 |

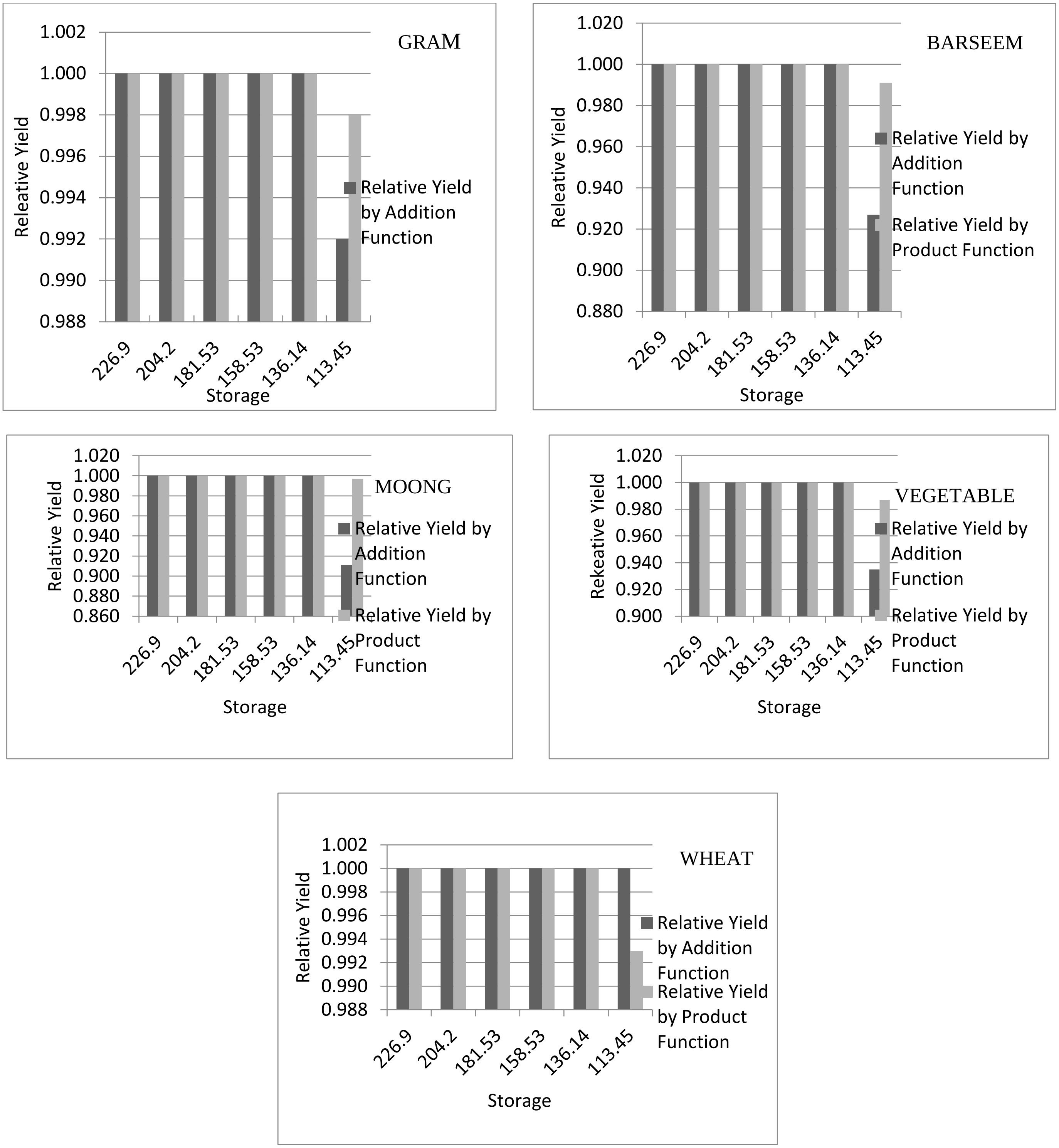



**Fig 2 : Comparison of relative yields of different crops at different storage levels of the reservoirs**

## CONCLUSION

The present study is conducted on the operation of an irrigation reservoir namely the Samrat Ashok Sagar Reservoir (Halali Project) in Vidisha and Raisen Districts of Madhya Pradesh. The study is based on irrigation water optimization for 5 crops in the command area in the dry weather (Rabi) season. The optimization technique employed is Genetic Algorithm solved on MATLAB Platform. Two formulations for optimization problem have been developed and solved. The first one is an additive model in which the weighted squared deviation of the demands and the actual releases for all the crops in all the seasons is added and the function is minimized. This is termed as the additive model. The weights are the relative yield factors for individual crops in the respective time periods. The second one is a multiplicative model in which the addition of the weighted squared deviation for all the crops in a season are multiplied with each other over the complete cropping season was supposed to be minimized. The models were applied to different levels of initial storage values of the reservoirs. The results of the study indicate that the model presented can be used to determine the optimal reservoir operation for irrigation planning. The optimization model developed in the present study allocates the water optimally amongst various crops in different time periods. The complete demands of all the crops for higher storage values in the reservoir is fulfilled but there is a competition amongst the crops at a reservoir storage level of 113.45 MCM The deficits in the supply and the allocations of deficits to maximize the possible relative yields is achieved at this storage. The results indicate that at this level of initial storage the major crop wheat gets full water as per the requirement when additive model is solved. The other crops suffer water deficits. When the multiplicative model is solved the other crops are at advantage at the cost of deficit in the wheat production. In general the multiplicative model yields better relative yield values even in the deficit conditions.

## REFERENCES


1. Adeyemo, J.A., 2011. "Reservoir operation using multi-objective evolutionary Algorithms- A review", Asian Journal of Scientific Research, Asian Journal of Scientific Research, ISSN 1992-1454 / DOI:10.3923/ajsr.

2. Ahmad, A., Shafie, A. E., Razali, S. F. M., and Mohamad, Z. S., 2014. "Reservoir Optimization in Water Resources: a Review", Water Resources Management, 28:3391–3405, pp 3391-3405, DOI 10.1007/s11269-014-0700-5

3. Ahmed, J.A., and Sarma, A.K., 2005. "Genetic algorithm for optimal operation policy of a multipurpose reservoir", Water resources management, vol-19, pp 145-161.

4. Allen, R. G., Pereira, L.S., Raes, D., and Smith, M., 1998. "FAO Irrigation and Drainage Paper No. 56 Crop Evapotranspiration (guidelines for computing crop water requirements)", FAO, Water Resources, Development and Management Service, Rome, Italy

5. Anand, J., Gosain, A.K., and Khosa, R., 2018. "Optimisation of Multipurpose Reservoir Operation by coupling SWAT and Genetic Algorithm for Optimal Operating Policy (Case Study: Ganga River basin)", Preprints (www.preprints.org) Posted: 23 March doi:10.20944/preprints201803.0199.v1 © 2018

6. Arunkumar, R., and Jothiprakash, V., 2011. "Optimal reservoir operation for hydropower generation Using differential evolution algorithm", ID:191 available on www.jba.gov.my/.../184-optimal-reservoir-operation-for-hydropower

7. Azamathulla, H.M., Wu, F. C., Ghani, A. A., Narulkar, S. M., Zakaria, N.A., and Chang, C. K., 2008. "Comparison between genetic algorithm and linear programming approach for real time operation", Journal of Hydro-environment Research. 2: p. 172-181.

8. Barros, F. V. F., Nascimento, L.S.V.N., Martins, E. S. P. R., and Reis Junior, D. S., 2008. "The Use of Multi-objective Optimization for Reservoirs' System Operation with an Evolutionary Algorithm: The case of the Metropolitan Region of Fortaleza, Brazil", 13th World Water Congress of IWRA, September, 01-04, Montpellier Conference

   https://iwra.org/member/congress/resource/abs721_article.pdf

9. Central Water Commission 2006 "Post Project Performance Evaluation Study of Samrat Ashok Sagar Project Madhya Pradesh", FINAL REPORT, M.P. Water and Land Management Institute WALMI Hills Right Bank of Kaliasote Dam B No 538, Ravishankar Nagar PO Bhopal

10. Chen, L., McPhee, J., and Yeh, W.W.G., 2007. "A diversified multi-objective GA for optimizing reservoir rule curves", Advances in Water Resources 30(5):1082-1093, http://repositorio.uchile.cl/bitstream/handle/2250/124937/Chen_Li.pdf?sequence=1

11. Dariane, A.B., and Moradi, A.M., 2008. "Reservoir Operating by Ant Colony Optimization for Continuous Domains (ACOR) Case Study: Dez Reservoir", World Academy of Science, Engineering and Technology 43

12. Doorenbos, J., and Kassam, A.H., 1979. "Yield response to water. FAO Irrigation and Drainage Paper No. 33", Rome, FAO.

13. East, V., and Hall, M.J., 1994. "Water resources system optimization using genetic algorithms", Hydroinformatics '94, Proc., 1st Int. Conf. on Hydroinformatics, Balkema, Rotterdam, The Netherlands225–231.

14. Goldberg, D.E., 1989. "Genetic algorithms in search optimization and machine learning", Addison-Wesley, Reading, Mass.

15. Jotiprakash, V., and Ganeshsan shanthi., 2006. "Single reservoir operating policies using genetic algorithm", of Water Resources Management vol.20: 917929

16. Labadie John, W., 2004. "Optimal operation of multi reservoir systems :state-of-the- art review", Journal of water resources planning and management, March/April, pp 93-110.

17. Mathur, Y.P., and Nikam, S. J., 2009. "Optimal Reservoir Operation Policies Using Genetic Algorithm", International Journal of Engineering and Technology Vol. 1, No. 2, June, Pp 793-8236

18. Mujumdar, P.P., and Narulkar, S., 1993. "Optimisation Models for Multi-reservoir Planning and Operation",

Indian National Committee on Hydrology, Roorkee, India, Vol.8. No. 1, pp. 29-52.

19. Neboh, N., Adeyemo, J., Enitan, A., and Olugbara Oludayo., 2015. "A Review on Applications of Evolutionary Algorithms to Reservoir Operation for Hydropower Production", World Academy of Science, Engineering and Technology, International Journal of Geological and Environmental Engineering, Vol:9, No:9,

20. Nicklow, J., Reed, P., Savic, D., Dessalegne, T., Harrell, L., Chan-Hilton, A., Karamouz, M., Minsker, B., Ostfeld, A., Singh, A., Zechman, E., 2010. "State of the Art for Genetic Algorithms and Beyond in Water Resources Planning and Management", J. Water Resour. Plan. Manag. 136,

21. Rani, D., and Moreira, M.M., 2010. " Simulation–Optimization Modeling: A Survey and Potential Application in Reservoir Systems Operation", Water Resource Manage 24:1107–1138, DOI 10.1007/s11269-009-9488-0

22. Reddy, M. J., and Kumar, N. D., 2005. "Multi objective differential evolution with application to reservoir system optimization", Journal of Computing in Civil Engineering, pp-861-878.

23. Reddy, M. J., and Kumar, N.D., 2006. "Optimal Reservoir Operation Using Multi-Objective Evolutionary Algorithm", Water Resources Management 20: 861–878 DOI: 10.1007/s11269-005-9011-1 C _ Springer

24. Reddy, M.J., and Kumar N. D., 2007 "Optimal reservoir operation for irrigation of multiple crops using elitist-mutated particle swarm optimization", Hydrological Sciences–Journal–des Sciences Hydrologiques, **52**(4) pp 686-701, August.

25. Scola Lu´ıs, A., Neto, O. M., Takahashi, R.H. C., and Cerqueira S´ergio, A. A. G., 2010. "Multi-objective Optimal Reservoir Operation", WCCI IEEE World Congress on Computational Intelligence July, 18-23, CCIB, Barcelona, Spain

26. Sharif and Wardlaw., 2000. "Multireservoir system optimization using genetic algorithms-Case study", J. computation in civil engineering 14(4).pp-255-263.

27. Tospornsampan,J., Kita, I., Ishii, M., and Kitamura, Y., 2005. "Optimization of a multiple reservoir system operation using a combination of genetic algorithm and discrete differential dynamic programming: a case study in Mae Klong system, Thailand", Paddy Water Environ 3: 29–38 DOI 10.1007/s10333-005-0070-y

28. Wardlaw and Sharif.,1999. "Evaluation of genetic algorithms for optimal reservoir system operation", J. water resource planning management., vol. 125(1), pp 25-33

29. Wurbs, R.A., 1991. "Optimization of Multiple-Purpose Reservoir System Operations: A Review of Modeling and Analysis Approaches", A report, January, Hydrologic Engineering Center U.S. Army Corps of Engineers, Davis, CA

30. Yang, J., 2012. "A New Particle Swarm Optimization Algorithm to Hierarchy Multi-objective Optimization Problems and Its Application in Optimal Operation of Hydropower Stations", Journal of Computers, vol. 7, no. 8, august.

31. Yeh, W.W.G., 1985. "Reservoir management and operations models: A state-of-the-art review", Water Resour. Research, Vol. 21, no. 12, pp. 1797—-1818, [Online]. Available: http://dx.doi.org/10.1029/WR021i012p01797