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EVALUATION OF EFFECT OF EVAPORATION LOSS ON RESERVOIR YIELD COMPUTATION

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ABSTRACT

Over the past several decades, many techniques have been studied for the reservoir operation. From these studies it has been observed that every case of a reservoir is unique from the operation point of view. A large number of factors affect the operation of a reservoir which includes topography, inflow, demand, evaporation losses, etc. Among these the evaporation losses have to be tackled carefully to optimize the reservoir system. In the present study, modeling is done for Urmodi Reservoir system in Krishna Basin in Maharashtra, India. The Linear Programming (LP) is used to determine the linearity effect of evaporation on yield computation. The yield computed by Genetic Algorithm (GA) uses the non-linear relationship of storage and water spread area. It is observed that the effect of evaporation computation is important in reservoir operation studies. In the present case study, it was found that the average annual storages and hence evaporation losses are higher by GA than LP. The reservoir annual yields by LP and GA are found to be 187.45 MCM and 197.66 MCM respectively. More losses by evaporation using GA resulted in lower annual yield.

***Keywords**: Reservoir operation, Urmodi reservoir, GA, LP, evaporation loss, continuous model*

INTRODUCTION

Irrigation planning and other water uses are dependent on the proper reservoir operation and management. It is observed that extensive irrigation practices tend to pay less attention to the reliability aspect of irrigation supply leading to unexpected failures during the low flow years. Reservoir operation is a complex task for a water manager. It involves a number of uncertainties of inflows, demands, seepage losses, etc. The reservoir system analysis of a reservoir depicts a fair picture of input, output and the associated environment. The optimization of reservoir system is mainly dependent on inflows and losses. The reservoir losses like seepage and evaporation play a crucial role in optimizing the reservoir system. The evaporation losses are of considerable magnitude and hence are incorporated in reservoir system analysis. The reservoir operation models are either linear or nonlinear. The present study deals with the effect of linear and non-linear relationship of reservoir storage and water spread area of reservoir for the evaporation loss computation. Although negligible or a constant value of evaporation loss is assumed in reservoir optimization studies, however a considerable effect of this assumption is observed on the reservoir optimization (Sivapragasam et al., 2009).

The reservoir operation has been an issue of great concern. Many researchers have implemented various techniques for the optimization of reservoir scheduling. But, very few studies have reported the effect of evaporation on the reservoir yields. Hence it is required to assess the impact of evaporation loss in reservoir optimization study. A comprehensive study of simulation, optimization and combination of these two was done by Deepti et al. (2010). The study discussed in detail about potential uses of the classical optimization techniques, computational intelligence (CI) techniques. Finally it was concluded that reservoir systems simulation-optimization softwares had been developed that employ Linear Programming (LP) and Dynamic Programming (DP) optimization. However, the need to develop more efficient decision support tools using CI and simulation was emphasized. The reservoir operation optimization for maximizing the hydropower production was studied using non-linear programming model for three different dependable inflow conditions (Arun kumar et al., 2012). A good storage at the end of the season was obtained by the developed model. The yield assessment is done using optimization and simulation techniques (Ghassan et al., 2013). The complete yield model and yield model were developed to estimate the maximum safe (firm) yield for the single reservoir system with allowable deficit. The study concluded that the complete model was more accurate to represent the system behavior. To allocate the water resources within a complex multiple reservoir system a Genetic Algorithm (GA) model was developed (Mohamed et al., 2011). The study concluded that evaluation of the system performance was essential to identify the preferred allocation strategy and insight into system behavior.

The necessity of incorporating the overflow spill and evaporation losses in the linear or nonlinear optimization models has been highlighted by Alcigeimes et al. (2010). The real time reservoir operation for irrigation demand fulfillment was studied for existing Chiller Reservoir system in Madhya Pradesh, India (Azamathulla et al., 2008). The study concluded that the GA model gives better yields as compared to LP model. A study was done using Genetic Programming (GP) and Penman model for evaporation loss estimation and reservoir scheduling indicating the equal performance of both the techniques (Sivapragasam et al., 2009). In this study, the GP was found to be more advantageous for modeling seepage losses. The

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optimization of single stage and two stage hedging policies was done using Genetic Algorithm (GA) (Chuthamat et al., 2014). The effect of the optimized hedging policies on reservoir performance was tested using Simulation. It was observed that the vulnerability was significantly reduced by using the optimized hedging rules. A comprehensive study was completed for Narmada Reservoir system emphasizing the usefulness of Linear Programming in reservoir operation studies (Dahe et al., 2002). A detailed study about potential application of Genetic algorithm can be read in Deb (1996) and Goldberg (1989). As GA starts from a randomly generated search space, it consumes much time to produce optimal solution. Hence a combined DP-GA approach was used for the optimal reservoir optimization of Mula Reservoir, in the State of Maharashtra in India (Deepti et al., 2016). The proposed DP–GA approach was found to be superior to both GA and DP in terms of less computational requirement and quality of the solution. Jothiprakashet al., (2006) developed a Genetic Algorithm model for Pechiparai reservoir in Tamil Nadu, India. The study concluded the effectiveness of GA in reservoir optimization. To maximize sum of irrigation releases into left and right main canal from the reservoir and to maximize annual power production was considered as the objective function in the study for Nagarjuna Sagar Reservoir system in India (Leela Krishna et al., 2018). The study highlighted the efficiency of Genetic Algorithm - Non-linear programming (GA-NLP) hybrid approach. Kenabathoet et al. (2005) studied hydrographic factors that are related to evaporation losses and the yield from the reservoir. The study concluded that beyond a particular range of yield, the effects of evaporation are more difficult to control. The multireservoir system of Brantas basin in East Java, Indonesia was studied using Genetic Algorithm (GA) and Discrete Differential Dymnamic Programming (DDDP). Both the methods produced close solutions. A comparative study was undertaken for the four-reservoir, deterministic, finite-horizon problem using Genetic Algorithm (GA) (Robin et al., 1999). The real-value coding, tournament selection, uniform crossover, and modified uniform mutation were used for the study. The study concluded that the GA had potential as an alternative to stochastic dynamic programming. A full optimization model was successfully developed and applied to Upper Penganga Project- Isapur reservoir in the Godavari River basin in Maharashtra, India. Linear Programming was applied for solving the optimization model (Sharma et al., 2011). A non-linear programming optimization model with an integrated soil/water balance was developed to determine the optimal reservoir release policies and the optimal cropping pattern (Somayeh et al., 2014). The proposed model was solved using a genetic algorithm (GA). The results indicate that for all weather conditions the total farm income and the total cropped area under deficit irrigation were larger than those under full irrigation.

The yield from the reservoir is the maximum amount of water that can be withdrawn in a given period of time. In the present study, the effect of evaporation loss over average annual yield estimationis studied. For this, the evaporation computation using LP and GA is done and the average annual yield from the reservoir is computed. The variation in yield computation by considering the linearity and nonlinearity effect between reservoir storage and water spread area is also studied.

STUDY AREA

The Urmodi Reservoir located in Krishna Basin in Satara District of Maharashtra State, India is considered in this study. It is located between 17°40’0” N Latitude and 73°54’40” E Longitude. The historical inflow data of 33 years from 1975 to 2007 is studied for the development of the model. It is observed that the average annual inflow into reservoir is 349.32 MCM out of which about 77.5% inflow occurs in the months of July and August. The evaporation rate in the months of March, April, May, and June have almost 57% share in the total annual evaporation of 1727mm. The average inflow into reservoir and the irrigation demand are shown in Fig. (1). Salient features of Urmodi reservoir are shown in Table 1.

Table 1: Salient features of Urmodi reservoir

Type of Dam	**Earthen dam with Gated Ogee spillway on left bank**
Maximum height of dam	50.10 m
Gross catchment area	116.86sq km
Gross capacity of reservoir	282.14 MCM *
Dead storage capacity of reservoir	8.867 MCM
Live storage capacity of reservoir	273.273 MCM

(*MCM- Million Cubic Meter)

METHODOLOGY

Linear programming

It is well known that the water balance equation is the governing equation for a reservoir operation. Linear programming is widely used modeling method in water resources engineering. The simplicity of programming, easy availability of software and handling of large number of constraints are the prominent features of a LP tool. Both the objective function and the constraints are linear in nature in Linear Programming method. Prior to more detailed stochastic optimization or simulation study, deterministic models using selected values of uncertain inputs are found to be useful (Sharma et al., 2011) for preliminary analyses of alternative plans.

The objective function of the present model is to maximize the annual yield (R) from the reservoir using deterministic continuous LP (DCLP) yield model. The mass–balance constraint equation, reservoir storage capacity constraints, overflow constraint, and evaporation loss constraints are used to optimize the objective function.

The **mass–balance constraint equation** represents the monthly storage continuity. It is given by

$$S_{j,t} + I_{j,t} - K_t R - Sp_{j,t} - E_t = S_{j,t+1} \forall\ j, t, \quad (1)$$

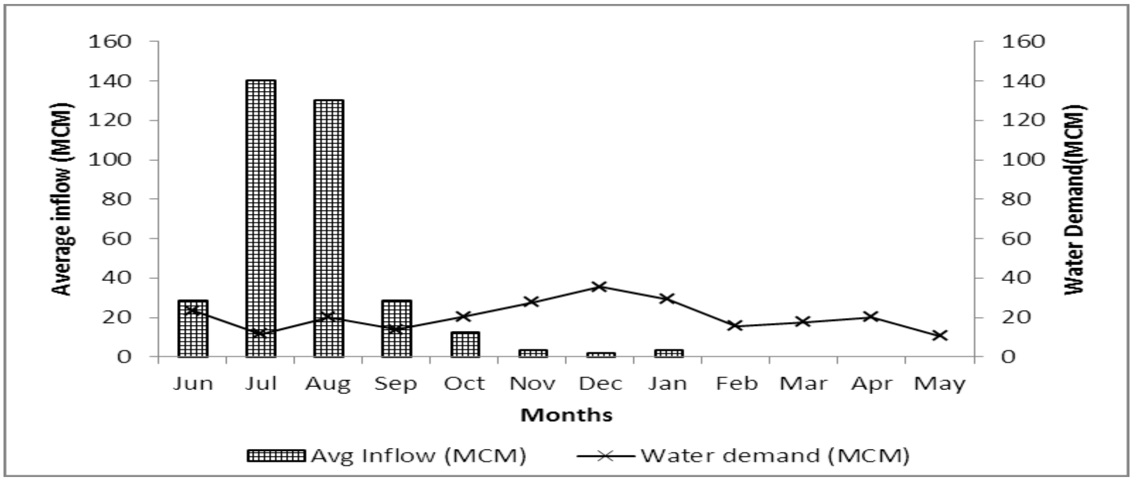

Fig.1. Monthly average inflow and water demand

Where, $S_{j,t}$ = initial storage in the month 't' in year 'j'; $S_{j,t+1}$= final storage in the month 't' in year 'j'; $I_{j,t}$ = inflow during the month 't' in year 'j'; E_t= Evaporation loss from the reservoir during time period 't' in year 'j'; $Sp_{j,t}$= Surplus from the reservoir during month 't' in year 'j'; K_t = Predetermined fraction of annual yield for the within year yield in period 't'

The reservoir **storage capacity constraint** is given by:

$$S_{min} \leq S_{j,t} \leq S_{max} \forall\ j,t \quad (2)$$

Where, S_{min}= Minimum Storage capacity of the reservoir in Mm^3; S_{max}= Maximum Storage capacity of the reservoir in Mm^3.

Overflow constraint: When the final storage in a month exceeds the reservoir capacity, excess amount is spilled over. It is given by:

$$Sp_{j,t} = S_{j,t+1} - S_{max} \quad (3)$$

and $Sp_j \geq 0$

Evaporation loss constraints: Evaporation loss in a month is calculated by assuming the linear relationship between the water surface area and the reservoir storage content above the dead storage level (Fig.2) (Aa = slope of area-capacity curve above dead storage level, which is assumed to be linear). The evaporation loss is the function of initial and final reservoir storage in a given month. The evaporation loss in a month when compared with the total average monthly evaporation loss gives the fraction of the annual evaporation.

$$E_t = \gamma_t E0 + [(S_{j,t} + S_{j,t+1})/2]\gamma_t El^r \forall\ j,t \quad (4)$$

where, E0= Fixed annual average evaporation volume loss due to dead storage; El^r= Average annual volume loss rate per unit of active storage volume; γ_t = Fraction of the annual evaporation from reservoir in the period (Fig.3).

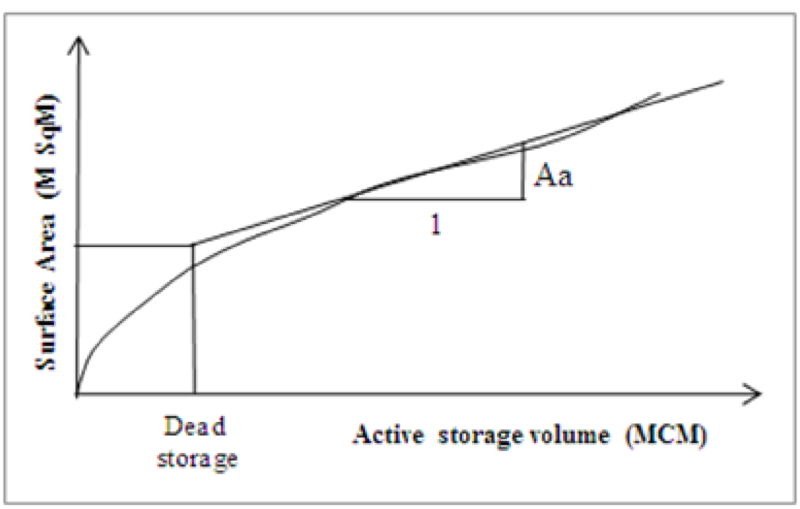

Fig. 2: Surface Area versus storage volume

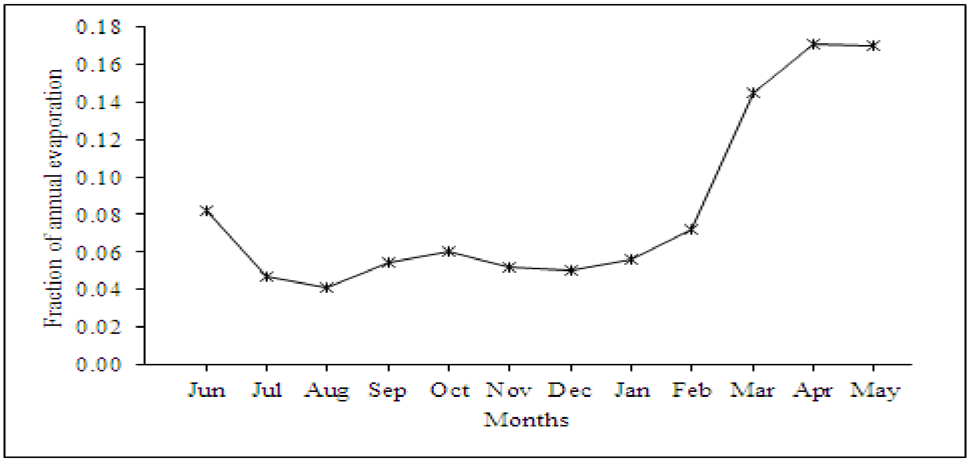

Fig.3. Monthly fraction of annual evaporation (Source: DPR, Urmodi Project)

Genetic Algorithm

Genetic algorithm (GA) is a search method based on the natural genetics and natural selection given by Darwin's Principle of "Survival of the fittest". The detailed descriptions of GAs and subsequent developments can be found in Goldberg (1989). The Genetic Algorithm (GA) can handle the nonlinearity of either objective function or constraints or both of them. Hence, a non-linear relation between the reservoir storage and water spread area is established to determine the periodically occurring evaporation loss. The volume loss due to evaporation is the product of water spread area and the evaporation depth in the month.A fitness curve equation obtained for the plot of the water spread area and storage capacity (Fig. 4), is given by $A=-7\exp(-09)s^4+5\exp(-06)s^3-0.0012s^2+0.1728s+0.3119$ (5)

Where, A= water surface area for reservoir storage's' in a month ($s \leq S_{max}$).

The GA is initiated by considering population of 10 chromosomes, 50% crossover probability, 0.001 mutation probability and 10 numbers of generations. After performing the sensitivity analysis, the optimal genetic parameters are found as: Population size 90, crossover probability 78%, mutation probability 0.004 and number of generations 80.

RESULTS AND ANALYSIS

The Linear Programming (LP) and Genetic Algorithms (GA) are applied for reservoir operation to compute the annual yield from the Urmodi Reservoir. The main objective of the modeling is to study the effect of evaporation losses on yield computation. The LINDO (**L**inear, **IN**teractive, and **D**iscrete **O**ptimizer) software is used to run the optimization model. The LP model does not require any initial state condition to be provided. The monthly storages, spilled quantity and the evaporation losses are calculated by using equations (1) through (4). Genetic Algorithm (GA) considers the nonlinear relation between water surface area and reservoir storage. The annual yield is considered as the decision variable in the present study. A typical flowchart for application of GA is shown in Fig. 5. The GA starts with generation of a random population of annual yield i.e. probable solutions. The length of the chromosome of decision variable consists of 16 binary bits. The randomly generated population of decision variables is undergone the genetic operations like selection, crossover and mutation to get the final optimum solution. In the present study "Roulette Wheel Selection method" is adopted for the fitness function evaluation.

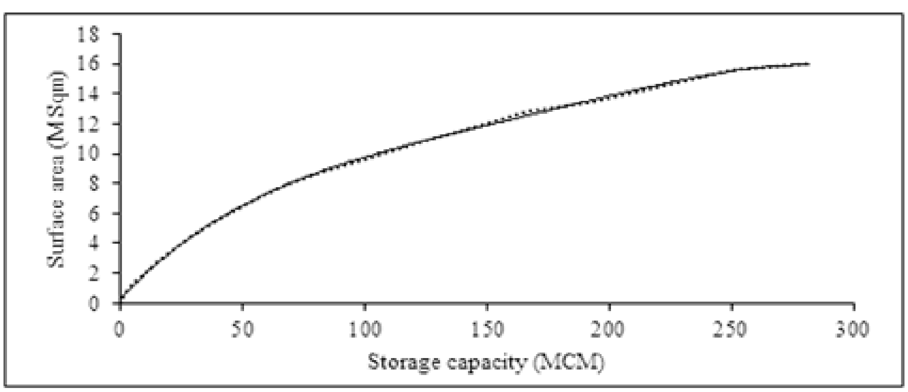

Fig.4 Storage capacity - Surface area relationship for Urmodi Reservoir

Hence, better the fitness, higher is the probability of being copied to the next generation. Thus, according to Darwin's theory of "the survival of the fittest", weak solutions are eliminated and strong solutions survive to form the next generation.In the crossover operation the genes of selected two chromosomes of decision variables are exchanged to obtain the best material from the parents. As the string length is small, one point crossover is adopted. The mutation follows the crossover process to inject a genetic material thereby a sudden change in the chromosome is observed. It helps the process not to get trapped into local optima.

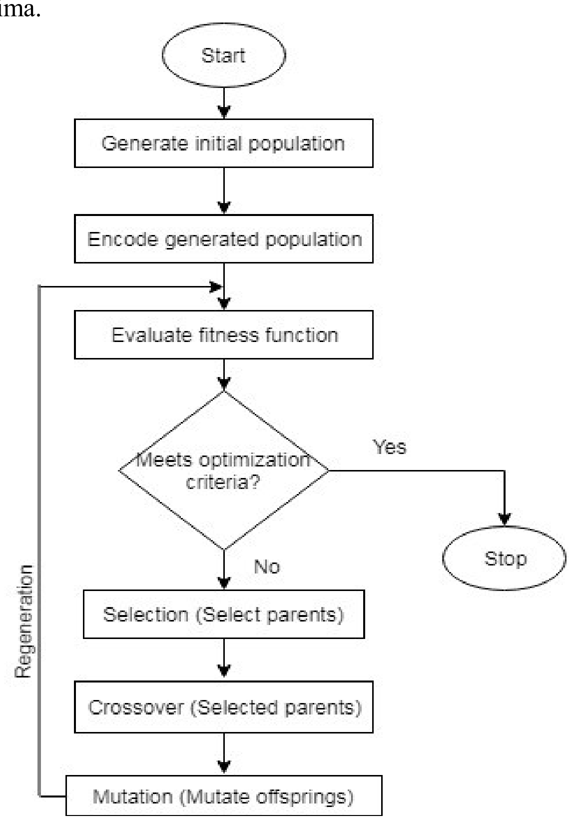

Fig.5. Flowchart of a typical GA model

The complete yield model is run by LP and GA and a comparative study of average annual yields is done. The average annual yields obtained by LP and GA are 199.76 MCM and 187.45 MCM respectively. It is observed that the monthly storages obtained by GA are comparatively higher than those obtained by LP (Fig.6). The LP results are based on the linearity assumption between reservoir storage and water spread area. The initial storage in LP is so adjusted that a global optimum solution is obtained. But the GA starts with the initial storage at dead storage level. This makes a difference in further calculations. The average monthly storage by GA is found to be 2.9 times higher than the average monthly storage obtained by LP. Therefore, lower evaporation losses by LP as compared to those by GA are observed (Fig.7). The average monthly evaporation losses by GA are found to be about 27.5 times the average monthly evaporation losses by LP. When the inflow exceeds the reservoir capacity, overflow occurs along the spillway of the dam. A comparative study of average monthly evaporation losses by LP and GA is shown in Fig.(8). In optimization process the average monthly spilled quantity is found to be nearly equal by both the LP and GA methods (Fig.9).

The average monthly water demand, storages and releases by LP and GA are shown in fig.10. The average monthly releases by LP are higher than the releases by GA. On an average, LP fulfills about 81% of the monthly targets while the GA fulfills about 76% of the demand in every month. It is observed that the average monthly storage by LP is less than that by GA.The average monthly storage by GA is about 3 times that by LP. From the relationship of the water spread area and storage capacity, it is observed that for higher storage, water surface area is found to be more. Therefore, the average monthly evaporation losses by GA are higher and found to be about 27 times than that by LP. However, the LP produces about 6% higher spills than GA. Hence, to conserve and utilize more quantity of water, if proper evaporation loss controlling methods are adopted, the reservoir will contain water in most of the periods in a year.

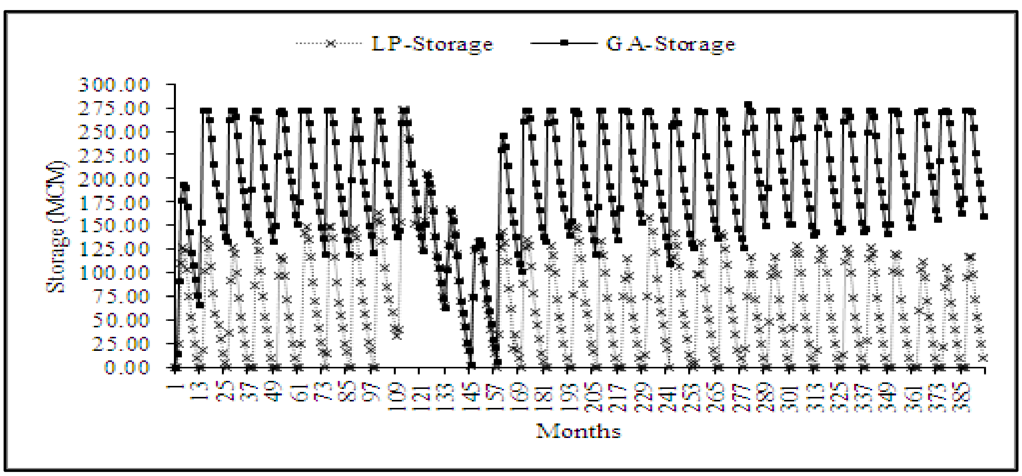

Fig.6. Monthly Storages by LP and GA methods

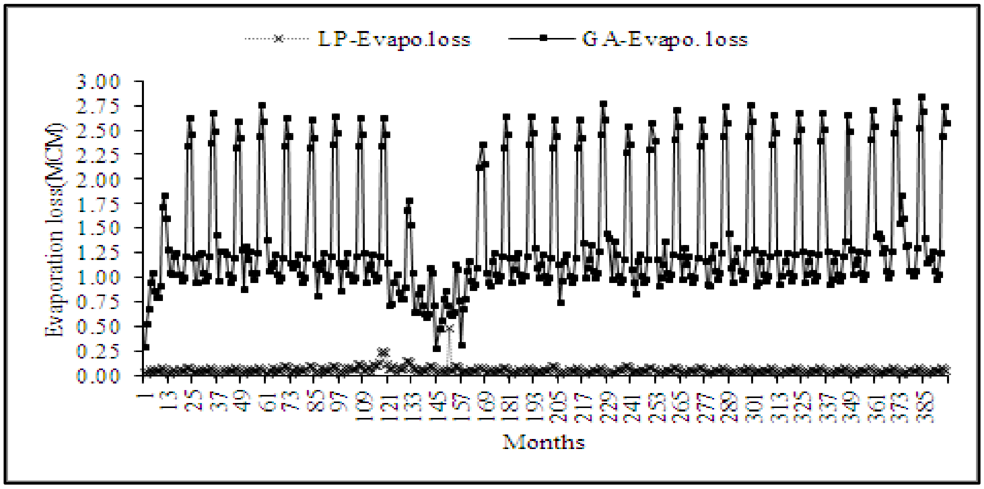

Fig.7. Evaporation losses by LP and GA methods

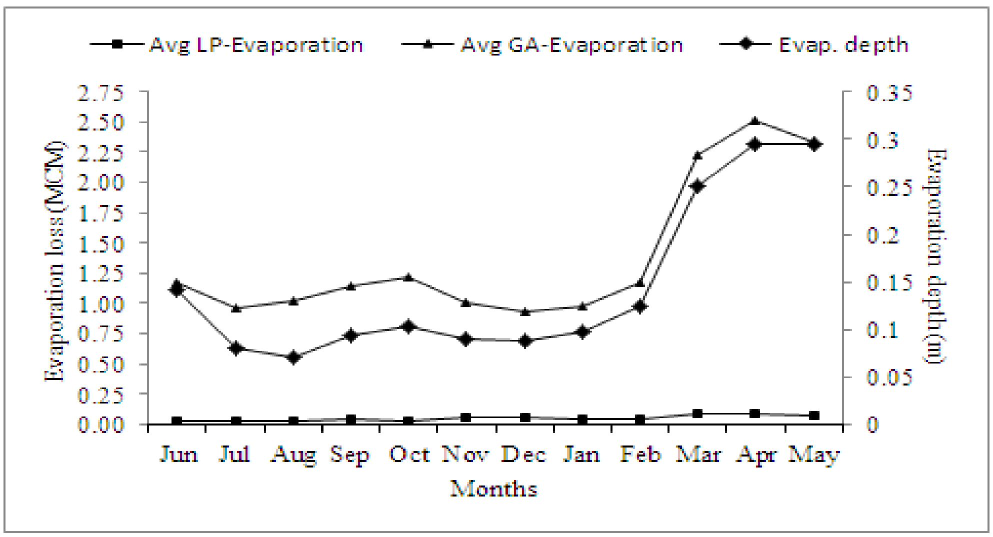

Fig.8. Average monthly evaporation depth and losses

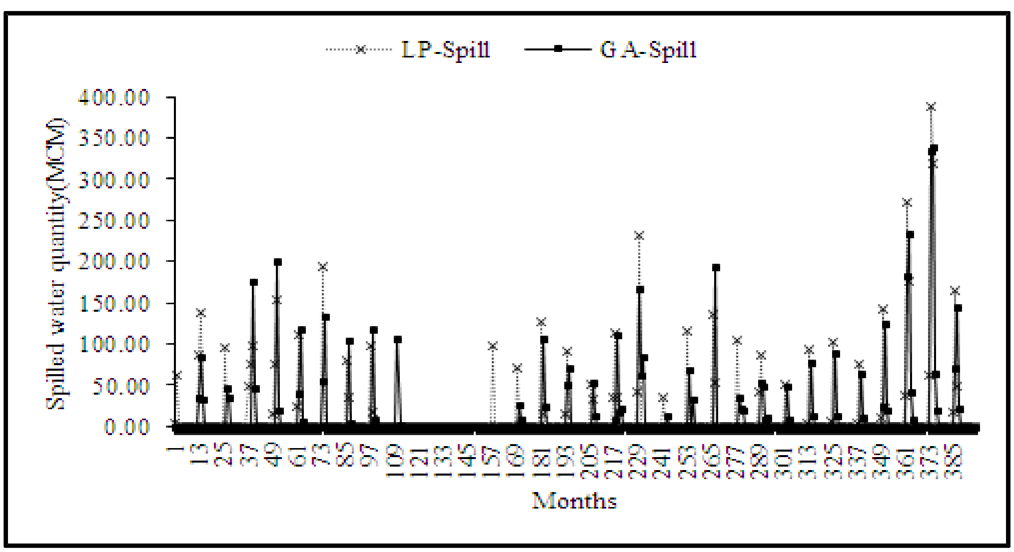

Fig.9. Spilled water quantity by LP and GA methods

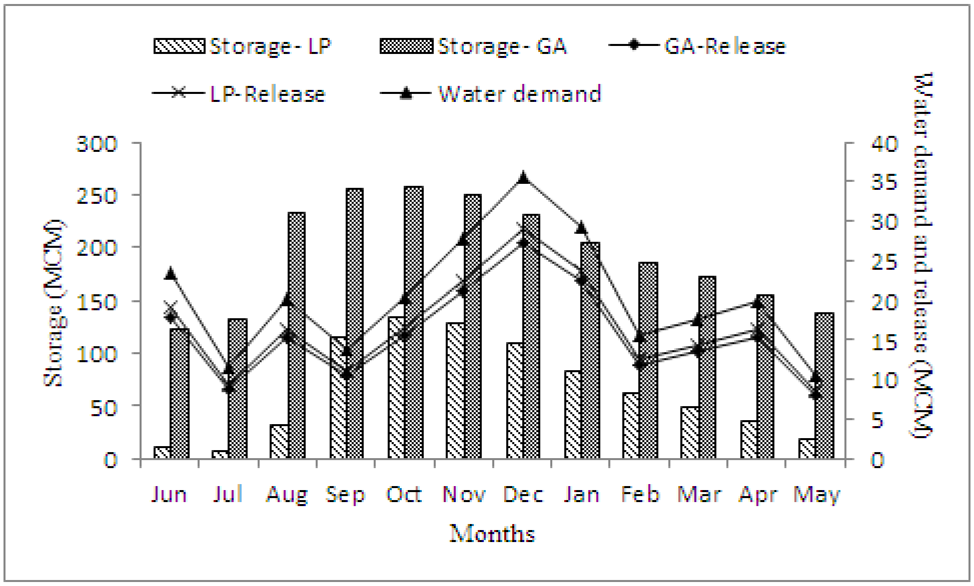

Fig.10. Average monthly demand, storage and release by LP and GA

CONCLUSIONS

The effect of evaporation loss on reservoir annual yield is studied for the Urmodi Reservoir in Krishna Basin, Maharashtra, India. The conventionally used Linear Programming (LP) and an Evolutionary algorithm i.e. Genetic Algorithm (GA) are used in the present study. The average annual yields obtained for the historic 33 years monthly inflow are 199.76 MCM and 187.45 MCM by LP and GA respectively. The evaporation loss is computed using linear relationship between water surface area and storage in the reservoir in Linear Programming method. The Genetic Algorithm uses nonlinear relationship between the water surface area and storage in the reservoir. Larger water surface areas for larger storages are observed by GA method that resulted in higher evaporation losses. However, the overflow spill in excess water condition is observed to be nearly equal by LP and GA methods varying by only about 5%, with higher spill by LP method. The present comparative study helps to conclude that the reservoir operation optimization by Genetic Algorithm results in lower annual yield than by Linear Programming. The average annual storages and hence evaporation losses are higher by GA. The average annual evaporation loss per average annual storage by GA and LP are found to be 0.00708 and 0.00075 respectively. The study reveals that the loss of evaporation greatly affects the annual yield from the reservoir which ultimately influences the reservoir scheduling. The consideration of linearity or non-linearity of relationships between water surface area and storage in the reservoir ultimately affects the yield estimation. Hence, proper evaporation loss preventive measures if applied will help to increase the yield from the reservoir.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

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