16 Genetic Algorithms in Irrigation Planning: A Case Study of Sri Ram Sagar Project, India

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Abstract

The present study deals with application of Genetic Algorithms (GA) in the field of irrigation planning. The GA technique is used to achieve efficient operating policy with the objective of maximum net benefits for the case study of Sri Ram Sagar Project, Andhra Pradesh, India. Constraints include continuity equation, land and water requirements, crop diversification considerations, and restrictions on storage capacities. Penalty function approach is used to convert constrained problem into unconstrained one. For fixing GA parameters, namely, crossover and mutation probabilities, the model is run for 7 values of crossover and 6 values of mutation probabilities. It is found that appropriate parameters such as number of generations, population size, crossover probability, and mutation probability are 200, 50, 0.6 and 0.01 respectively for the present study. Maximum benefits obtained by LP solution is 2.4893 Billion Rupees where as these are 2.3903 Billion Rupees by GA (with a fitness function value of 2.3678 Billion Rupees). Results obtained by GA are compared with Linear Programming solution and found to be reasonably close.

Keywords: Genetic Algorithms, Irrigation Planning, Linear Programming, Sri Ram Sagar Project, India

16.1 Introduction

Many real world problems involve two types of problem difficulties i.e., multiple, conflicting objectives (instead of a single optimal solution, competing goals give rise to a set of compromise solutions denoted as pareto-optimal) and a highly complex search space which is difficult to be solved by exact methods. Thus efficient optimization strategies are required that can deal with both difficulties. *Genetic Algorithms* (GA) possess several characteristics that are desirable for this type of problems and make them preferable to classical optimization methods. Goldberg (1989) described the nature of genetic algorithms of choice by combining a *Darwinian survival of the fittest* procedure with a structured, but randomized, information exchange to form a canonical search procedure that is capable of addressing a broad spectrum of problems. Genetic Algorithms are search procedures based on the mechanics of natural genetics and natural selection. They combine the concept of artificial survival of fittest with genetic operators abstracted from nature to form a robust search mechanism. Goldberg (1989) identified the following significant differences between GAs and more traditional optimization methods:

- GAs work with a coding of the parameter set, not with the parameters themselves.
- GAs search from a population of points, not a single point.
- GAs use objective function information, not derivatives or other auxiliary knowledge.
- GAs use probabilistic transitions rules, not deterministic rules.

16.1.1 Working Principle of Genetic Algorithms

Any nonlinear optimization problem without constraints is solved using Genetic Algorithms involving basically three tasks, namely, Coding, Fitness evaluation and Genetic operation. First of all, decision variables are identified for the given optimization problem. These decision variables are coded into some string like structures. For coding the decision variables, binary coding is used. This coded string is called Chromosome. The length of chromosome depends on the desired accuracy of the solution. It is not necessary to code all the decision variables in the same sub string length.

Fitness function is first derived from objective function and is used in successive genetic operations. Genetic operators require that the fitness function should be nonnegative. If the problem is of maximization, fitness function is taken as directly proportional to the objective function. The fitness function value of a string is known as the string's fitness.

Once the fitness of each string is evaluated, the population is operated by three common operators for creating new population of points. They are reproduction, crossover and mutation. Reproduction selects good strings in a population and forms a mating pool. In this paper Roulette wheel simulation is used for the selection of good strings. In crossover operator, two strings are picked from the mating pool at random and some portions of the strings are exchanged between the strings. A single point crossover operation is performed by randomly choosing a crossing site along the string and by exchanging all bits on the right side of the crossing site. The mutation operator changes 1 to 0 and 0 to 1 with a small mutation probability, p_m, within the string. Mutation creates points in the neighborhood of the current point, which help in local search around the current solution. It is also used to maintain diversity in the population.

The newly created population using the above operators is further evaluated and tested for termination. If the termination criterion is not met, the population is

iteratively operated by the above three mentioned GA operators and evaluated. This process is continued until termination criterion is met. One cycle of these operations and the subsequent evaluation procedure is known as a generation. The constrained problem, if any, is converted into unconstrained problem by using penalty function method. In this process, the solution falling outside the restricted solution region is considered at a very high penalty. This penalty forces the solution to adjust itself in such a way that after some generations it will fall into restricted solution space. In penalty function method a penalty term, corresponding to the constraint violation is added to the objective function. Generally bracket operator penalty term is used.

$$F_i = f(x) + \in \sum_{j=1}^{k} \delta_j (\phi_j)^2 \qquad (16.1)$$

Where F_i is fitness value, $f(x)$ is objective function value. k is total numbers of constraints, $\in$ is -1 for maximization and +1 for minimization. δ_j is penalty coefficient and ϕ_i is amount of violation. Once the problem is converted into unconstrained problem, the rest of the procedure remains the same. Excellent description of Genetic Algorithms is given by Deb (1995, 1999).

16.1.2 Necessity of Mathematical Modeling in Irrigation Planning

Need for efficient integrated management of an irrigation system is keenly felt due to growing demand for agricultural products, escalating cost of supplying water to farmer's fields and stochastic nature of water resources. Due to dwindling supply of irrigation water the profit conscious irrigators wish to so allocate the water as to maximize the net benefits with competing alternative crops. Investor's choice is further complicated by the fact that the allocation of water is required to be optimized over time, among the crops and also among the competing units of the same crop simultaneously. To meet the requirements, mathematical models and irrigation management methodologies are essential for optimum command area planning. In the present study, the concept of Genetic algorithms and irrigation planning problem are integrated for the case study of Sri Ram Sagar Project, Andhra Pradesh, India. The study is divided into four sections. Section 16.2 gives a brief literature review. Section 16.3 describes the case study followed by mathematical modeling. Section 16.4 analyses results obtained from mathematical model. Section 16.5 gives conclusions followed by references.

16.2 Literature Review

Various authors reported applications of various models in irrigation planning which are explained in brief. Lakshmi Narayana and Rajagopalan (1977) used Linear Programming (LP) model for maximizing the irrigation benefits for Bari

Doab basin in North India. Sensitivity analysis on the tube well capacity, the area available for irrigation, the operation costs for canals and tube wells etc., are also carried out. Loucks et al. (1981) discussed in detail the micro level irrigation planning with a detailed example. Multiobjective analysis is also reported in their studies. Irrigation planning studies using LP are reported by Maji and Heady (1980), Tandaveswara et al. (1992), Garg and Ali (1998). Srinivasa Raju and Nagesh Kumar (1999) proposed a crop-planning model with the objective of maximizing irrigation benefits for a typical irrigation system. Vedula and Nagesh Kumar (1996) developed an integrated model for irrigation planning for a reservoir system in Karnataka, India. Sabu Paul et al. (2000) proposed a multilevel approach based on stochastic dynamic programming for irrigation planning in Punjab, India. Kuo et al (2000) used Genetic Algorithm based model for irrigation project planning for a case study of Delta, Utah with the objective of maximization of net economic benefits for a culturable command area of 394.6 ha. They identified the optimum number of generations, population, crossover and mutation probabilities as 200, 50, 0.6 and 0.02 respectively. The present study deviates at least in two aspects (1) this study uses GA model for irrigation planning in Indian context. (2) A comparison is made between the solution obtained from GA model and that obtained by Linear Programming model.

16.3 Irrigation System and Mathematical Modeling

Sri Ram Sagar Project (SRSP) is a state sector major irrigation project located in Godavari River basin in Andhra Pradesh, India. Its head works are located in Pochampadu village in Nizamabad district of Andhra Pradesh at $18^0 58'$ N latitude and $70^0 20'$ E longitude. Salient features of Sri Ram Sagar project are presented in Table 16.1. Location map of SRSP is presented in Fig 16.1.

Table 16.1. Salient Features of Sri Ram Sagar Project

Item	Value
Type of Dam	Gravity
Length of Earth Dam	13.640 km
Length of Masonry Dam	0.958 km
Total Length of Dam	14.598 km
Maximum height of Masonry Dam	42.67 m
Gross Storage Capacity	3173 Mm^3
Full Reservoir Level (FRL)	332.5 m
Water Spread Area at FRL	434.8 Mm^3
Design flood Discharge	45300 cumecs
Culturable Command Area (stage 1)	1,78,100 ha

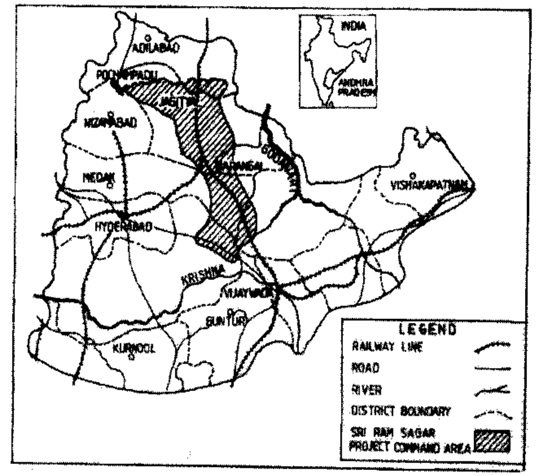

Fig 16.1. Location Map of Sri Ram Sagar Project

The climate of the area is subtropical and semi-arid. There is an extreme variation in temperature with average maximum and minimum values of 42.2^0 C and 28.6^0 C. The average relative humidity for the period from July to September remains above 80% whereas for April to June it is 65%. The evaporation loss varies from 124.3 mm in October to 386.3 mm in April. Rainfall is the primary source of water. The average rainfall of the study area is 944 mm out of which 800 mm falls during June to October. The culturable command area (CCA) of the project (stage 1) is 178,100 ha. Crops grown in the command area are Paddy (rice), Sorghum, Maize, Groundnut, Chillies and Sugarcane in both summer (Kharif) and winter (Rabi) seasons.

Mathematical modelling of the objective function with the corresponding constraints is explained below. The net benefits (*BE*) under different crops from command area of SRSP are to be maximized. Mathematically it can be expressed as

$$BE = \sum_{i=1}^{10} B_i A_i \tag{16.2}$$

Where i = Crop index [1 = Paddy (S), 2=Maize (S), 3= Sorghum (S), 4=Groundnut (S), 5=Paddy (W), 6= Maize (W), 7=Sorghum (W), 8=Groundnut (W), 9= Chilies (TS), 10=Sugarcane (P)].
S = Summer, W = Winter, TS =Two season, P = Perennial, t = Time index (1=January, ..., 12=December). *BE* = Net benefits from the whole planning region (Indian Rupees); B_i = Net benefits from the crops (excluding costs of water, fertilizers, labour employment etc) in Indian Rupees per hectare; A_i = Area of crop i grown in the command area (ha).

The model is subject to the following constraints.

16.3.1 Continuity equation

Reservoir operation includes water transfer, storage, inflow and spillage activities. Water transfer activities consider transport of water from the reservoir to the producing areas through canals to meet the water needs. A monthly continuity equation for the reservoir storage (Mm^3) (neglecting evaporation and other losses) can be expressed as

$$S_{t+1} = S_t + I_t - R_t ; t = 1,2,......12 \qquad (16.3)$$

Where S_{t+1} = Reservoir storage in the reservoir at the end of month t (Mm^3); I_t = Monthly net inflows into the reservoir (Mm^3); R_t = Monthly releases from reservoir (Mm^3).

16.3.2 Crop area restrictions

The total cropped area allocated for different crops in the command area in a particular season should be less than or equal to the Culturable Command Area (*CCA*).

$$\sum_i A_i \le CCA \quad i = 1, 2, 3, 4, 9, 10 \quad \text{Summer season} \qquad (16.4)$$

$$\sum_i A_i \le CCA ; i = 5, 6, 7, 8, 9, 10 \quad \text{Winter season} \qquad (16.5)$$

Where *CCA* = Culturable Command area (Ha). Crops of two seasons, namely, Chillies and Sugarcane (indices 9 and 10) are included in both the equations because they occupy the land in both the seasons.

16.3.3 Crop water diversions

Crop water diversions for crop i in month t (CWR_{it}) are obtained from the project reports. During the absence of any crop activity, CWR_{it} is taken as zero. Total water releases from Sri Ram Sagar reservoir must satisfy the irrigation demands of the region.

$$\sum_{t=1}^{12} \sum_{i=1}^{10} CWR_{it} A_i - R_t \le 0; t = 1,2;......12 \qquad (16.6)$$

Where CWR_{it}= Crop water diversions for crop i in month t (meters)

16.3.4 Canal capacity restrictions

Releases from reservoirs cannot exceed the canal capacity.

$$R_t \le CC; t = 1,2,.........12 \qquad (16.7)$$

The maximum volume of water the canal can transport each month is calculated as CC = 0.0864 x 30.4 x (canal capacity in cumecs)

16.3.5 Live storage restrictions

Reservoir storage volume S_t in any month t must be less than or equal to the maximum live storage capacity of the reservoir.

$$S_t \le \text{LSP} \; ; t = 1,2,............,12 \qquad (16.8)$$

Where *LSP*= Maximum live storage capacity of Sri Ram Sagar reservoir (Mm^3)

16.3.6 Crop diversification considerations

Since the command area lies in a region, which predominantly depends on agricultural economy, the planners want to ensure production of certain cash crops in addition to food crops. The targets are based on the existing cropping pattern.

$$A_i \ge A_{i.\min}; i = 1,2,.........10 \qquad (16.9)$$

$$A_i < A_{i.\max}; i = 1,2,.........10 \qquad (16.10)$$

Where $A_{i,min}$ and $A_{i,max}$ are minimum and maximum allowable limits of the area under crops. All the above information including inflows are obtained from reports and from discussion with officials of the project. Additional information is also obtained from agricultural department and Marketing society etc.

16.4 Results and Discussion

Penalty function approach is used to convert constrained problem into unconstrained problem with a reasonable penalty function value. For fixing the GA parameters, namely, crossover and mutation probabilities, the model is run for different values of crossover and mutation probabilities. Seven values of crossover probability i.e., 0.6, 0.75, 0.8, 0.85, 0.9, 0.95, 1.0 and six values of mutation probabilities i.e., 0.01, 0.03, 0.05, 0.07, 0.1, 0.12 are chosen with a population size of 50 and maximum number of generations 200. Fig 16.2 presents maximum fitness

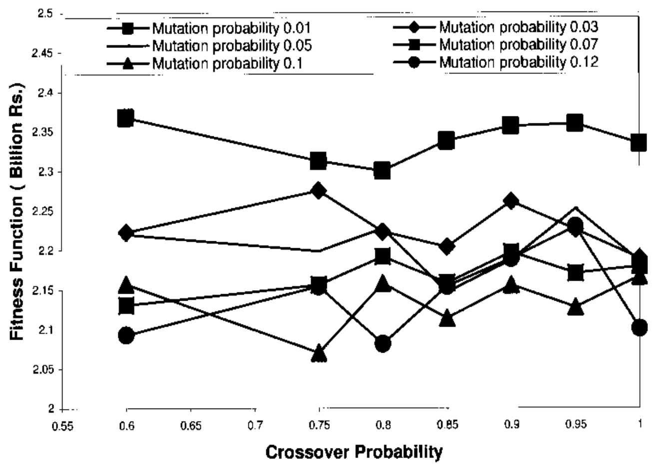

Fig 16.2. Comparison of Fitness Function Values for Various Crossover and Mutation Probabilities

function values for above mutation and crossover probabilities. Results obtained are compared in terms of total fitness function values in Fig 16.2 and number of generations in Fig. 16.3. It is observed from Fig 16.2 that for mutation probability value of 0.01 and for various crossover probabilities, each solution maintains its identity by deviating from other sets of solutions. Among these, the maximum fitness function value of 2.3678 Billion Rupees is achieved for crossover probability value of 0.6 and mutation probability value of 0.01 and this combination is used for further analysis.

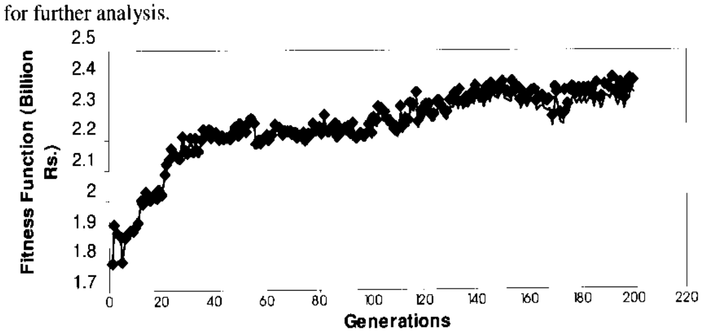

Fig 16.3. Comparison of Fitness Function Values for various Generations.

Fig 16.3 presents number of generations and corresponding fitness function values for the above selected probabilities. Maximum fitness function value occurred at generation 192 with a population of 50.

Efforts are also made to compare the solution of Genetic Algorithm (GA) with Linear Programming (LP) algorithm. Table 16.2 presents cropping pattern obtained by both the methods, which are self-explanatory.

Table 16.2. Crop Plans from the Planning Model for Maximization of Net Benefits

S .No.	Crops and related parameters	Unit	Solution from		% deviation between GA and LP
			GA	LP	
1	Paddy (s)	1000ha	29.43	30.00	1.90
2	Maize (s)	1000ha	29.37	30.00	2.10
3	Sorghum (s)	1000ha	49.71	50.00	0.58
4	Groundnut (s)	1000ha	8.950	9.000	0.55
5	Paddy (w)	1000ha	21.71	22.00	1.32
6	Maize (w)	1000ha	27.38	30.00	8.73
7	Sorghum (w)	1000ha	42.11	50.00	15.7
8	Groundnut (w)	1000ha	9.831	10.00	1.70
9	Chillies (ts)	1000ha	6.130	6.200	1.13
10	Sugarcane (ts)	1000ha	8.140	8.200	0.73
	Irrigated area	1000ha	247.0	259.8	4.92
	Net Benefits	Billion Rs.	2.3903	2.4893	3.97

s = Summer; w = Winter; ts=Two season

It is observed from Table 16.2 that maximum percentage crop acreage deviation of 15.78 and 8.73 occurs for Sorghum (w) and Maize (w) when comparing solution of LP with GA where as these are 1.9 % and 2.1% for Paddy (s) and Maize (s). Maximum benefits obtained by LP solution is 2.4893 Billion Rupees where as these are 2.3903 Billion Rupees by GA (with a fitness function value of 2.3678 Billion Rupees). Irrigated area and net benefits are deviated by 4.92% and 3.97% as compared to LP solution. Fig 16.4 presents graphical representation of crop acreages. Fig 16.5 presents release policy obtained by both the methods. It is observed that LP solution yields more releases in the months of January, February, May, August and September and releases obtained by the solution of GA is more for other months.

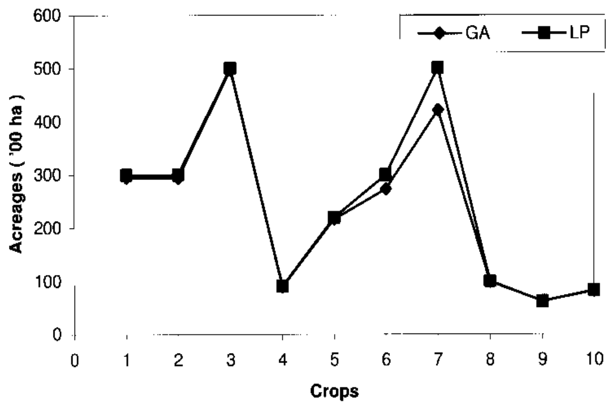

Fig 16.4. Comparison of Cropping Pattern

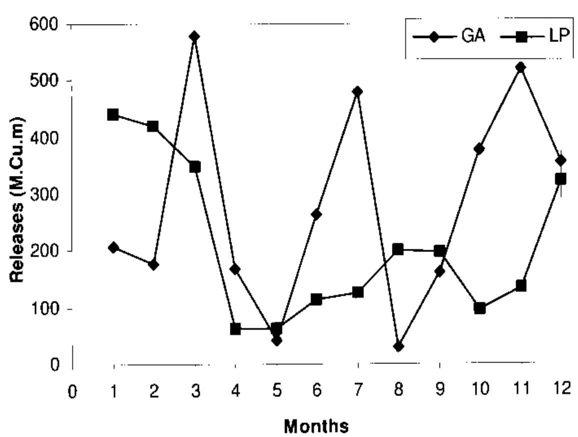

Fig 16.5. Comparison of Monthly Release

Fig 16.6 presents storage policy for the reservoir as obtained by both the methods. It is observed that reservoir reaches zero storage in the month of June and July as observed from the solution of LP whereas these are 49.46 and 782.40 as observed with GA solution. It is observed from above analysis and results that solutions obtained by both GA and LP are reasonably close. However, the solution obtained by GA for irrigation planning problem is to be further refined and investigated for number of factors such as penalty function values, efficient selection of mutation and crossover probabilities, generation and population which are targeted for further study.

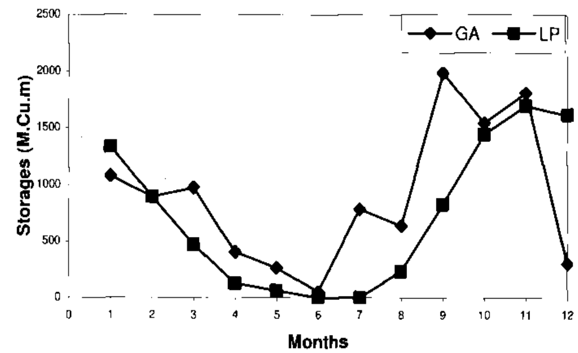

Fig 16.6. Comparison of Monthly Storage

16.5 Conclusions

The present study develops a GA based mathematical model for thecase study of Sri Ram Sagar Project, Andhra Pradesh, India for optimising net benefits from an irrigation system with the constraints such as continuity equation, land and water requirements, crop diversification considerations, canal capacity and storage restrictions. The results obtained from the GA model are compared with those obtained from Linear Programming optimisation model. The observations from the above study are as follows.

1. Maximum benefits obtained by LP solution is 2.4893 Billion Rupees where as these are 2.3903 Billion Rupees by GA (with a fitness function value of 2.3678 Billion Rupees).

2. It is observed that solutions obtained by both GA and LP are reasonably close. Irrigated area and net benefits obtained by GA are deviated by 4.92% and 3.97% as compared to LP solution.
3. Appropriate GA parameters identified from this study are: Number of generations =200, Population size=50, Crossover probability =0.6 and Mutation Probability=0.01.

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