USE OF GENETIC ALGORITHMS APPROACH FOR IRRIGATION PLANNING IN MAN MADE LAKES

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ABSTRACT

The present study deals with the application of Genetic Algorithms (GA) for irrigation planning. The GA technique is used to evolve optimum cropping pattern for maximizing net benefits for the case study of Jayakwadi Irrigation project, Maharashtra, India. Constraints include continuity equation, land and water requirements, crop diversification, storage and canal capacity etc. Penalty function approach is used to convert constrained problem into an unconstrained one. For fixing GA parameters the model is run for three selection functions, three cross over operators, four mutations for population size of 50 and generations 200. It is observed that combination of tournament selection, simple cross over and boundary mutation is found to be suitable.

INTRODUCTION

Agriculture is the back bone of Indian economy and irrigation is integral part of agriculture in India. This is necessitated due to spatial and temporal variation of rainfall distribution and its erratic nature due to the failure of the monsoon. In this regard good irrigation management, efficient operation and maintenance of irrigation systems are essential for the sustainability of irrigated agriculture which may results in better performance, better crop yields and sustained production. In addition components that may help in this process are enforcement of a suitable cropping pattern, preparation of contingency plans for the supply of inputs, namely, credit, seeds, fertilizers and pesticides. Recent times, there is growing interest in the field of irrigation management to integrate with system analysis techniques. With this back ground, the objective of the present study is aimed to achieve maximum net benefits corresponding to optimum cropping pattern and operating policy. Genetic Algorithms (GA) is used as the solution methodology. The following sections present the case study, mathematical model for irrigation planning, description of Genetic Algorithms, results and discussion followed by conclusions.

CASE STUDY

The Jayakwadi irrigation project is a major irrigation project consisting of a two reservoir system, namely, Paithan and Mazalgaon, located on the Godavari river, Maharasthra, India. The project is mainly meant for irrigation. Two canal systems are originating from Paithan reservoir, namely Paithan left bank canal (PLBC) and Paithan right bank canal (PRBC) having culturable command areas of 1,42,000 ha and 42,000 ha, respectively. After some distance downstream (along the length of PRBC), Mazalgaon reservoir exists with the source of supply from Sindphana river, a tributary of Godavari river. There is 93, 885 ha command area under Mazalgaon reservoir and the canal system is termed as Mazalgaon right bank canal (MRBC). Fig. 1 presents the schematic diagram of this two reservoir system. Gross and live storage capacities for Paithan reservoir are 2909 Mm^3, 2170 Mm^3 (i.e., 1 $Mm^3 = 10^6$ m^3). These are 453.64 Mm^3, 311.30 Mm^3 for Mazalgaon reservoir respectively. Crops in the command area are Sugar-cane, Banana, Chillies, Cotton, Sorghum, Paddy, Wheat, Gram and Groundnut. Project covers five districts (district means cluster of villages), namely Aurangabad, Ahmednagar, Bhir, Parbhani, Nanded in Maharashtra state (Raju and Duckstein, 2003).

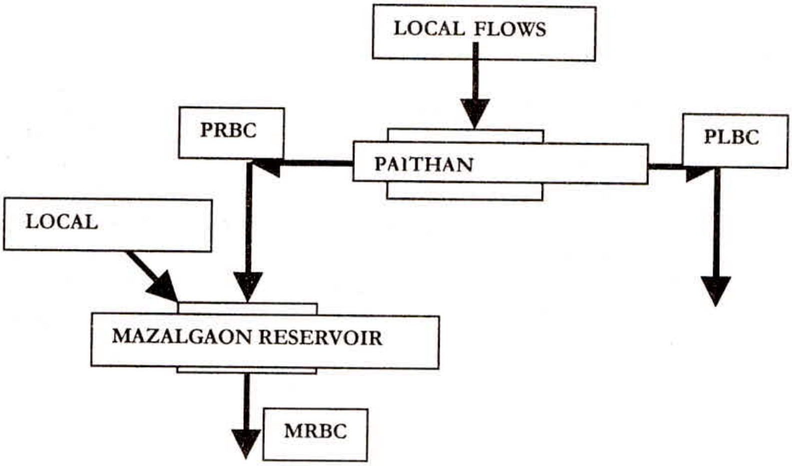

Fig 1. Schematic diagram of Jayakwadi reservoir system

Mathematical modeling is as follows: The net benefits (*BE*) under different crops from command areas of PLBC, PRBC, MRBC are to be maximized. These are obtained by subtracting the cost of surface water from gross benefits of crops (excluding costs of fertilizers, labor employment etc). Mathematically it can be expressed as

$$BE = \sum_{i=1}^{10} BL_i AL_i + \sum_{i=1}^{10} BR_i AR_i + \sum_{i=1}^{10} BM_i AM_i - C_w \sum_{t=1}^{12} (RLR_t + RM_t) \qquad (1)$$

where i = crop index [1 = Sugar-cane(P), 2=Banana(P) , 3=Chilies(TS) , 4=Cotton (TS), 5=Sorghum(S), 6=Paddy(S), 7=Sorghum (W), 8=Wheat (W), 9=Gram (W), 10=Groundnut(HW)], S = Summer, W = Winter, TS =Two season, HW =Hot weather, P = Perennial, t = Time index (1=January, ..., 12=December). *BE* = Net benefits from the whole planning region (Indian Rupees); BL_i ,BR_i , BM_i = Gross benefits from the crops (excluding costs of fertilizers, labor employment etc) from the command areas of PLBC, PRBC, MRBC respectively (Indian Rupees); AL_i , AR_i , AM_i = Area of crop i grown in the command areas of PLBC, PRBC, MRBC (ha); C_w = Cost of surface water (Rs/Mm^3); RLR_t = Total water releases from Paithan reservoir to command areas of PLBC and PRBC (Mm^3); RM_t = Water releases from Mazalgaon reservoir to command area of MRBC (Mm^3). The model is subjected to constraints such as

Continuity Equation

Reservoir operation includes water transfer, storage, inflow and spillage activities. A monthly continuity equation for the reservoir storage (Mm^3) can be expressed as

$$SLR_{t+1} = SLR_t + I_t - ELR_t - RLR_t - OLR_t ; t = 1,2,.......12 \quad (2)$$

Where SLR_{t+1} = End of month reservoir storage in the Paithan reservoir (Mm^3); I_t = Monthly net inflows into the Paithan reservoir (Mm^3); ELR_t = Monthly net evaporation volume (Mm^3) ; OLR_t= Overflows from Paithan reservoir (Mm^3). The above constraint assumes that the monthly inflows into the reservoir are known with certainty. When uncertainty is incorporated into the inflow terms, the above equation changes to

$$\Pr(SLR_{t+1} - SLR_t + ELR_t + RLR_t + OLR_t \geq I_t) \geq \alpha ; t = 1,2,......12 \quad (3)$$

or else

$$SLR_{t+1} - SLR_t + ELR_t + RLR_t + OLR_t \geq I_t^{\alpha} ; t = 1,2,......12 \quad (4)$$

Where I_t^{α} is inverse of the cumulative distribution of inflows at dependable level α .

Crop Area Restrictions

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

$$\sum_i AL_i \leq CCA \quad ; i=1,2,3,4,5,6 \quad \text{Summer season} \quad (5)$$

$$\sum_i AL_i \leq CCA \quad ; i=1,2,3,4,7,8,9 \quad \text{Winter season} \quad (6)$$

$$\sum_i AL_i \leq CCA \quad ; i=1,2,7,8,9,10 \quad \text{Hot weather season} \quad (7)$$

Crops 1, 2 are perennial and thus included into all the seasons; Crops 3, 4 are of two-season crops and occupy the land both in the Summer and Winter seasons; Crop 10 is a hot weather crop. Other Winter crops 7, 8, 9 are also included into equation (7) because crops 7, 8, 9 occupy the land in January, whereas crops 7, 8 occupy the land also in February, whereas crop 10 starts in January and ends by May. So crop 10 shares the same CCA with other winter, Perennial crops for some portion of time. Similar analysis is employed for command areas of PRBC and MRBC, respectively.

Crop Water Diversions

Monthly crop water diversions CWR_{it} are obtained from the project reports. In absence of any crop activity, CWR_{it} is taken as zero. Total water releases from Paithan reservoir must satisfy the irrigation demands of PLBC, PRBC.

$$RLR_t - \sum_{i=1}^{10} CWR_{it} AL_i - \sum_{i=1}^{10} CWR_{it} AR_i = 0; t = 1,2;......12 \quad (8)$$

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

Canal Capacity Restrictions

Overflows from Paithan reservoir and irrigation demands of PRBC cannot exceed the right bank canal capacity. Also irrigation demands of PLBC cannot exceed the left bank canal capacity.

$$\sum_{i=1}^{10} CWR_{it} AR_i + OLR_t \leq CCR; t = 1,2,.........12 \quad (9)$$

$$\sum_{i=1}^{10} CWR_{it} AL_i \leq CCL; t = 1,2,.....................12$$

(10)Where CCL, CCR = Canal capacities of PLBC, PRBC (Mm^3)

Live Storage Restrictions

Reservoir storage volume SLR_t in any month t must be less than, or equal to, live storage of Paithan reservoir.

$$SLR_t \leq \text{LSP} \ ; \text{t} = 1,2,...,12 \quad (11)$$

Where LSP= Live storage of Paithan reservoir (Mm^3)

Similar constraints are formulated for Mazalgaon reservoir. 75% dependable inflow scenario is used both for Paithan and Mazalgaon reservoirs. All the input parameters including inflows are obtained from the Jayakwadi project report (1985). These are not presented here due to space limitation. Some additional information is obtained from agricultural department and Marketing society, etc.

GENETIC ALGORITHMS

Genetic Algorithms (GA) technique (Houck et al., 1996). is applied to solve the above planning problem. Genetic Algorithms are search procedures based on the natural genetics and natural selection. They combine the concept of the survival of fittest with genetic operators extracted from nature to form a robust search mechanism. Any optimization problem without constraints is solved using genetic algorithms involving basically three tasks, namely, coding, fitness evaluation and genetic operation. Fitness function is derived from the objective function and is used in successive genetic operations. If the problem is for 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 operators, reproduction, crossover and mutation for creating new population of points. In reproduction, good strings are selected to form a mating pool. The newly created population is further evaluated and tested for termination to decide the maximum number of generations. If the termination criterion is not met, the population is iteratively operated further by the above three operators and evaluated. One cycle of these operations and its subsequent evaluation is known as a generation. This process is continued until termination criterion of preset maximum number of generations is met. If the problem is constrained, it is converted into an unconstrained problem by using penalty function method. In this process, the solution falling outside the restricted solution region is considered at a high penalty. This penalty forces the solution to adjust itself in such a way that after some generations it will fall into the restricted solution space. In penalty function method, a penalty term, corresponding to the constraint violation, is added to the objective function (Michalewicz, 1994).

$$F_i = f(x) + \in \sum_{j=1}^{k} \delta_j (\phi_j)^2 \qquad (12)$$

where F_i is fitness value, $f(x)$ is objective function value, k is total number of constraints, $\in$ is -1 for maximization and +1 for minimization, δ_j is penalty coefficient and ϕ_j is amount of violation. Once the problem is converted into an unconstrained problem, rest of the procedure remains the same. A detailed description of Genetic Algorithms for irrigation planning is given by Raju and Kumar (2004).

RESULTS AND DISCUSSION

The Genetic algorithm (GA) approach discussed above has been implemented in Genetic Algorithms for Optimization Toolbox (GAOT). Real-coded GA is implemented in the present paper. Each module of the algorithm is implemented using a Matlab function (Houck et al., 1996). This provides for easy extensibility as well as modularity. Since the objective function is of maximization in nature (net benefits), $\in$ value is -1 (as per equation 12). In this case value of fitness function is proportional to objective function. Penalty function approach is used to convert the constrained problem into an unconstrained problem with a reasonable penalty value. Also Genetic Algorithms is dependent on various parameters such as population, generations, cross over and mutation probabilities. To account for this, various combinations are tried to arrive at a suitable combination which maximizes the fitness function. Total 36 combinations were analyzed namely, three selection functions (Roulette Wheel Selection RWS; Normalized Geometric Selection NGS; Tournament Selection TS), three cross over operators (Arithmetic cross over A; Heuristic cross over H; Simple cross over S), four mutations (Boundary mutation B; Non Uniform Mutation NUF; Multi Non Uniform Mutation MNUF; Uniform mutation UF) for population size 50 and generations 200. Resulting combinations are (1) RWS,A ,B (2) RWS,H,B (3) RWS,S,B (4) RWS,A,NUF (5) RWS, H, NUF (6) RWS, S,NUF (7) RWS, A, MNUF (8) RWS, H, MNUF (9) RWS, S, MNUF (10) RWS, A, UF (11) RWS, H,UF (12) RWS, S,UF (13) NGS,A ,B (14) NGS,H,B (15) NGS,S,B (16) NGS,A,NUF (17) NGS, H, NUF (18) NGS, S,NUF (19) NGS, A, MNUF (20) NGS, H, MNUF (21) NGS, S, MNUF (22) NGS, A, UF (23) NGS, H,UF (24) NGS, S,UF (25) NGS,A ,B (26) NGS,H,B (27) NGS,S,B (28) NGS,A,NUF (29) NGS, H, NUF (30) NGS, S,NUF (31) NGS, A, MNUF (32) NGS, H, MNUF (33) NGS, S, MNUF (34) NGS, A, UF (35) NGS, H,UF (36) NGS, S,UF. Fig. 2 presents variation of net benefits for 36 different combinations. It is observed from Fig. 2 that combination 27 (Tournament selection, Simple cross over, Boundary mutation) is found to be suitable combination due to its higher fitness function value of 1.8907 x 10^9 Rupees (correspondingly 2.1482 x 10^9 Rupees of net benefits) among considered combinations for the given population size and generations. Fig 3 presents total irrigated areas of crops corresponding to 36 combinations. Maximum irrigated area of 3,54,000 ha is observed for combination 27. Cropping pattern, storage and release policy corresponding to combination 27 is discussed in detail below.

Lower and upper bounds are fixed based on existing cropping area and future needs of the growing population. These are (42.6, 64), (21.3,32.6), (42.6,65.2) ,(355,400), (170.4,240), (142,180), (213,326) ,(355,400) ,(71,100) , (42.6,65) for crops Sugar-cane(P), Banana(P), Chilies(TS) , Cotton (TS), Sorghum(S), Paddy(S), Sorghum (W), Wheat (W), Gram (W), Groundnut(HW) for PLBC. For PRBC these are (12.6, 25.2), (6.3,12.6), (12.6,25.2), (105,120) ,(50.4,70), (42,64) , (63,80) ,(105,125), (21,42) (12.6,25.2). These are (28.2,36.4), (14.1,18.2), (28.2,36.4), (235,270), (113,160), (94,118), (141,200), (235,370), (47,74), (28.2,36.4). All the above values are in '00ha. Table 1 presents irrigated areas of crops suggested by the planning model for all the three regions PLBC, PRBC and MRBC of the project. It is observed that Chillies in PRBC is 1.617 times more than the lower limit. All the other crops in the PLBC, PRBC are reaching their upper bounds. In case of MRBC, Banana,

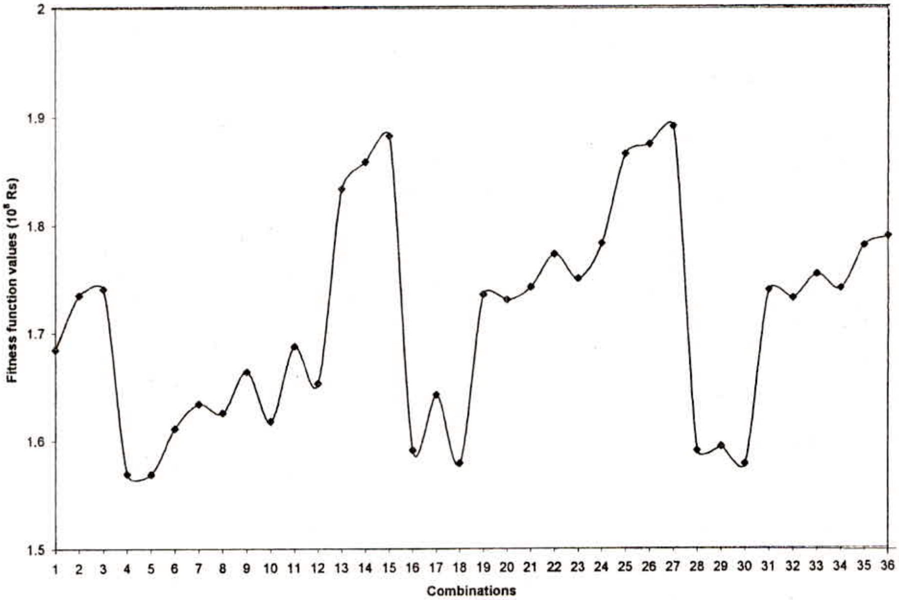

Fig 2. Graph showing the variation of fitness function values with various combinations (Generations 200 and population size 50)

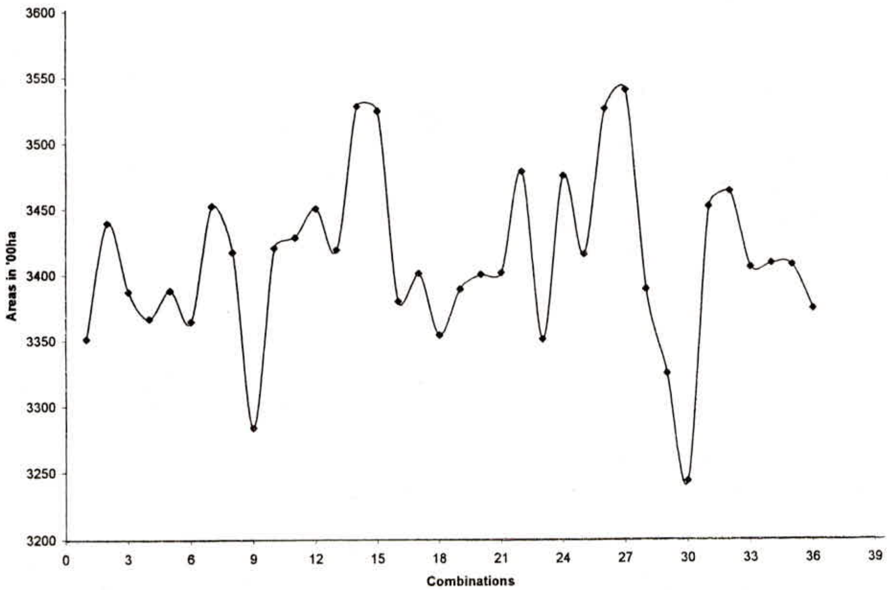

Fig 3. Graph showing the variation of irrigated areas with various combinations (Generations 200 and population size 50)

Table 1. Cropping areas of both the canals of Paithan reservoir
(PLBC & PRBC) and Mazalgaon right bank canal (MRBC)
(Combination 27 and Generations 200, population size 50)

Crop	Season	Cropping area ('00ha) PLBC	Cropping area ('00ha) PRBC	Cropping area ('00ha) MRBC
Sugarcane	P	64.00	25.20	36.40
Banana	P	32.60	12.60	14.10
Chillies	TS	65.20	20.38	31.26
Cotton	TS	400.00	120.00	260.30
Sorghum	S	240.00	70.00	113.00
Paddy	S	180.00	64.00	105.00
Sorghum	W	326.00	80.00	141.00
Wheat	W	400.00	125.00	279.12
Gram	W	100.00	42.00	70.11
Groundnut	HW	65.00	25.20	32.72
Total		1872.80	584.38	1083.02

Sorghum (S) and Sorghum (W) are satisfied at their lower levels. Sugarcane has reached its upper limit. All the other crops in MRBC are between lower and upper limits. Total area irrigated by the model is 1,87,280 ha, 58, 438 ha, 1,08,302 ha for PLBC, PRBC and MRBC respectively with corresponding irrigation intensities of 131.80%, 139.10%, 115.30%. Net benefits from the project are Rs. 2.1482 x 10^9 and benefits per ha of CCA is Rs.7730 ha. It is observed that empty storage exists in Paithan reservoir in the month of February, May and August. But at no time the Paithan reservoir reached its maximum live storage level which may be due to higher demands. It is observed that releases from Paithan reservoir in the month July are zero which requires further investigation. The above conclusions are based on the number of combinations proposed in the present study. This may change for various population sizes, generations, real or binary coding, penalty function value and types of penalty functions.

CONCLUSIONS

In the present study, a GA based model is developed for evolving an optimum cropping pattern for the case study of Jayakwadi irrigation project, Maharashtra, India. The conclusions from the study are as follows.

1. In regions PLBC, PRBC , MRBC irrigated areas are 1,87,280 ha, 58,438 ha, 1,08,302 ha respectively with corresponding irrigation intensities of 131.80%, 139.10%, 115.30%.
2. Combination of Tournament selection, Simple cross over, Boundary mutation is found to be suitable combination due to its higher fitness function value of 1.8907 x 10^9 Rupees (correspondingly 2.1482 x 10^9 Rupees of net benefits) among considered combinations for the given population size and generations.
3. Net benefits from the project per ha of CCA is Rs.7730.
4. Genetic Algorithms is found to be an effective optimization tool for the present study of irrigation planning and can be used for more complex systems involving non-linear optimization.

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REFERENCES

Houck, C.R, Joines, J and Kay, M. (1996), A genetic algorithm for function optimization: a Matlab implementation. ACM Transactions on Mathematical Software.

Jayakwadi project report (1985), Jayakwadi irrigation project, Government of Maharashtra, India.

Michalewicz, Z. (1994), Genetic Algorithms+ Data Structures= Evolution Programs, AI Series, Springer-Verlag, New York.

Raju, K.S and Duckstein, L. (2003), Multiobjective fuzzy linear programming for sustainable irrigation planning: an Indian case study, Journal of Soft Computing, Vol.7, No. 6, pp. 412-418.

Raju, K. S and Kumar, D. N. (2004), Irrigation Planning using Genetic Algorithms, Water Resources Management, Vol. 18, No. 2, pp.163-176.