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OPTIMUM CROPPING PATTERN FOR SRI RAM SAGAR PROJECT : A LINEAR PROGRAMMING APPROACH

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ABSTRACT

Linear Programming (LP) irrigation planning model is developed for the evaluation of irrigation development strategy and applied to a case study of Sri Ram Sagar Project, Andhra Pradesh, India with the objective of maximization of net benefits.Uncertainty in the inflows arising out of the uncertainity in the rainfall is tackled through chance constrasined (stochastic) programming. Inflows at four levels of dependability viz., 75%,80%, 85% and 90% are considered in the present study to obtain various possible optimal cropping patterns and optimal operating policies. it is observed that net benefits at 75% dependability level are 68.8% more than those at 90% dependability level. Comparison of the results indicated that the methodoloty is quite versatile and can be used in other similar situations, as well,with suitable modifications.

Introduction

Increasing demands for agricultural products with limited water resources lead to irrigation planing and management problems, In addition, the conflicting objectives of individual monetary benefits and social benefits, invevitability of uneconomical crops and providing employment to labour make the problems rather more complex. For efficient and scientific solutions of these problems, ground water is also to be optimally extracted and combined with surface water to meet the requirements. In this regard mathematical models and irrigation management methodologies are to be integrated for optimum utilization of resources, In present study monthly Linear Programming (LP) irrigation planning model is developed and applied to a case study of Sri Ram Sagar Project with the objective of maximizing net benefits. The model is subjected to number of constraints such as continuity equation, land and water requirements, water quality, storage restrictions, crop surface and ground water releases etc.

Linear Programming (LP) technique is widely used by many researchers for irrigation planning problems for real case studies. Lakshmi narayana and Rajagopalan (1971) used LP model for maximizing and irrigation benefits for Bari basin in Northern 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) discused in detail the micro level irrigation planning with a detailed example. Multi objective analysis is also reported in their sudies. Pawar and Murthy (1991) proposed a crop planning model with the objective of maximizing irrigation benefits for a typical irrigation district. Extensive sensitivity analysis is carried out for water and fertilizer application on the crop calendar. It is concluded that farm planning can be used as an extension tool to convince the farmers on the need for changing the crop planning in the region. More details on application of LP are available from Tandaveswara et al. (1992), Gart and Ali (1998) among others.

Irrigation System Under Study

Sri Ram Sagar Project (SRSP) is a state sector major irrigation project of Telengana region of Andhra Pradesh, India, on the river Godavari. It is situated at Pochampadu village in Nizamabad district of Andhar Pradesh. Global co-ordinates of the dam site are 18 58' North latitude and 70 20' East longitude. Salient features of Sri Ram Sagar Project (SRSP) are presented in Table 1.

Table.1

Salient features of Sri Ram Sagar Project

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 heighty of Masonry Dam	42.67 m
Gross Storage Capacity	3173 Mm3
Full Reservoir Level (FRL)	332.5 m
Water Spread Area at FRL	434.8 Mm2
Design Flood Discharge	45300 cumecs
Culturable Command Area (stage 1)	1,78,100 ha

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 is varying from 124.3 mm in October to 386.3mm in April. Rainfall is the primary source of water table at suitable levels through ground water requirements directly and maintains the water table at suitable levels through ground water recharge. The average rainfall of the study area is 944 mm out of which 800 mm falls during June to October and the Command Area Development Authority is planning to utilize the available ground water, particularly in the month of June, to avoid delay in sowing crops in the summer (Kharif) season which otherwise affect winter (Rabi) season. Subsidy for cost of ground water pumping is under consideration. The maincrops grown in the command area are Paddy, Maize, Sorghum, Groundnut, Vegetables, Pulses, Chillies and Sugarcane. Location map of Sri Ram sagar Project is shown in Fig 1. Brief details about Linear Programming and its application (mathermatical modelling) to the case study of SRSP are discussed below.

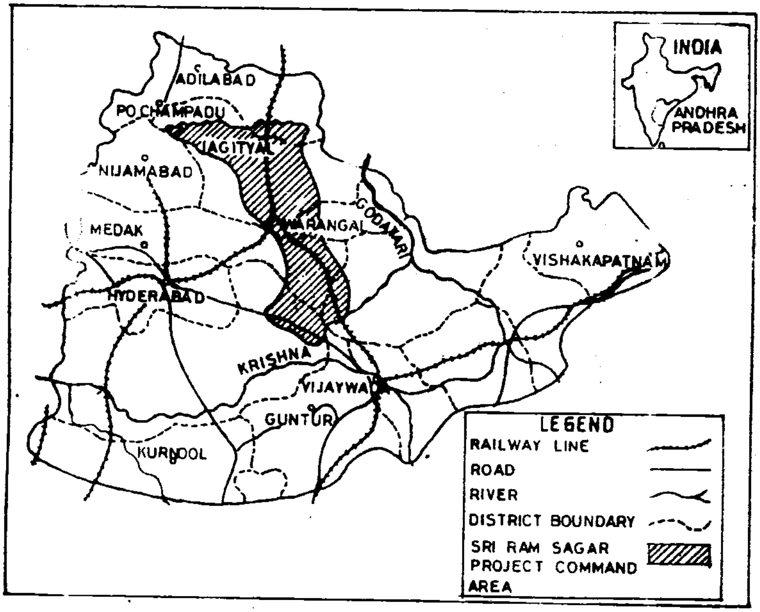

Fig. 1. Location Map of Sri Ram Sagar Project

Linear Programming (LP)

Linear Programming (LP) deals with the problem of allocating limited resources among competing activities in an optimal manner. In a more convenient matrix notation, a typical LP problem (Maji and Heady, 1980) can be written as

$$\text{Max/(Min) } Z = C^T x \quad (1)$$

Subject to the constraints

$$Ax \geq B \quad (2)$$

$$\text{and } x \geq 0 \quad (3)$$

Where C is a (nX1) vector known contants, x is a (n x 1) vector of decision variables,A is a (m x n) matrix of known constants and B is a (mx 1) vector of constants. The problem is to find a set of x, the decision variables, that maximize (or minimize) the objective function Z (equation 1) and satisfies the equations 2 and 3.

When uncertainty is associated with important variables, a comprehensive analysis is needed to evaluate the expected performance of the system for random events. These problexs can be tackled through stochastic optimization techniques. Chance Constrained Programming is one of the methods in this category (Loucks et al., 1981).

$$\text{Max / (Min) } Z=C^{T}x \qquad (4)$$

subject to the constraints

$$\Pr(AX \geq B) \geq \alpha \qquad (5)$$

and $x \geq 0$

where Pr (.) is the probality operator and is the level of dependability (reliability). The equation 5 may be violated at most (1000) percent of the time. In other words, this approach requires a constraint to hold with specified level of confidence or to be violated with known level of risk. The conversion of the probabilistic constraints to deterministic ones requires the knowledge about probability distribution function (F_B) of random variable B, i.e.

$$A\,x \geq F_B^{-1}(\alpha) \qquad (7)$$

Where $F_B^{-1}(\alpha)$ is inverse of cumulative distribution function of random variable B at level α.

Mathematical Modeling

The net benefits (BEM) from the irrigated as well as unirrigated areas under different crops are obtained by subtracting the costs of surfaces water, fertilizer and labour from the gross revenue for different crops. Maximization of net benefits can be expressed as

$$\text{Max } BEM = \sum_{i=1}^{16} B_i\,A_i - P_{sw}\sum_{t=1}^{12} R_t - P_{gw}\sum_{t=1}^{12} GW_t - \sum_{f=1}^{3}\sum_{i=1}^{16} F_{fi}\,A_i\,P_f - P_l\sum_{t=1}^{12}\sum_{i=1}^{16} L_{it}\,A_i \qquad (8)$$

in which ι = Crop index [1=Paddy(s), 2=Maize (s), 3=Sorghum(s), 4=Groundnut(s), 5=Vegetables(s), 6=Pulses (s), 7=Paddy (srf), 8=Groundnut(srf), 9=Paddy (w), 10=Groundnut(w), 11=Pulses(w), 12=Maize(w), 13=Sorghum(w), 14=Vegetables(w), 15=ChilliesOw), 16=Sugarcane(ts)]; s=Summer, w=Winter, ts=Two season; srf=Summer rainfed, t=Mnthly index 1=January, 2=February, 3=March, 4=April, 5=May, 6=June, 7=July, 8=August, 9=September; 10=October; 11=November; 12=december);f=Fertiliser index(1= Nitrogen, 2=Phosphorous, 3=Potash), Ai=Area of crop i (ha); Bi=Unit gross return from i the corp (Rs); Psw=Unit surface water cost (Rs / Mm3); Rt=monthly canal water release (Mm3); Pgw=Unit ground water cost(Rs/Mm3; GWt = Monthly gorund water requirement (Mm3); Ffit=Quantiy of fertiliser of type F for crop i (tons/ha); P_T=Unit cost of fertiliser type f (Rs); Pl=Unit wage rate (rs);Lit=Labour days required for each hecatare of crop i in month t; Rs = Rupees

The above objective function is subject to the following constraints:

a) Continuity equation

Reservoir operation includes water transfer, storage, inflows and spillage activities. Water transfer activities consider transport of water from the reservoir t the producing areas through canals to meet the water needs. The monthly continuity equation for the reservoir storage (Mm3) is expressed as

$$S_{t+1} = S_t + Q_t - EV_t - R_t - RDS_t - OSR_t \; ; \qquad t = 1,2,......12 \qquad (9)$$

Where S_{t+1} = End of month reservoir storage volume; Q=Monthly net inflow volume : EV_t Monthly net evaporation volume: RDS_t = Downstream requirements: OSR_t = Spilled volume. The above constraint assumes that the monthly inflows into the reservoir is known with certainty. When stochasticity is incorporated in the inflow terms, the above equation changes to.

$$S_{t+1} = S_t + EV_t + R_t + RDS_t + OSR_t \geq q^{\alpha}_t ; \qquad t = 1,2,.....12 \qquad (10)$$

Where q^{α}_t is the inverse of the cumulative distribution function of inflows at dependable level α in which stochstic considerations are included.

b) Crop land requirements.

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

$$\sum_i Ai \leq CCA; \; i = 1,2,3,4,5,6,7,8,15,16 \text{ for summer crops} \qquad (11)$$

$$\sum_i Ai \leq CCA; \; i = 9,10,11,12,13,14,15,16 \text{ for winter crops} \qquad (12)$$

Crop of two seasons. namely, Chillies and Sugarcane (indices 15 and 16) are inluded in both the equations because they occupy the land in both seasons.

c) Water requirements of crops

Monthly crop water requirements should not exceed the maximum available water from both surface and ground water sources.

$$\sum_{t=1}^{12}\sum_{i=1}^{16} Ai \; CWR_{it} \leq R_t + GW_t \qquad (13)$$

Where CWR_{it} is crop water requirement for unit area of crop i in month t.

d) Ground water withdrawals

The total ground water withdrawals in a year should be less than or equal to the estimated annual ground water potential (TGW) of the aquifer i.e.,

$$\sum_{t=1}^{12} GW_t \leq TGW \qquad (14)$$

e) Water quality

The concentration of total dissolved solids (TDS) of the ground water pumped from the quifer and reservour water in the canal network must fulfil a specified irrigation water quality standard QSand can be expressed as

$$CGW\ GW_t + CRW\ R_t \leq QS\ (GW_t + R_t) \qquad (15)$$

Where CGW, CRW are average concentration of total dissolved solids in ground water and reservoir water (mg/L).

f) Capacity of canal

The total release from the reservoir cannot exceed the canal capacity

$$R_t + RDS_t \leq CC_t \qquad t = 1,2 \ldots\ldots 12 \qquad (16)$$

The maximum volume of water the canal can transport each month is calculated as

$$CC_t = 0.0864 \times (\text{Canal capacity cumecs}) \times \text{Number of days in month}$$

g) Minimum and maximum reservoir storages

Reservoir storage volume S_t in any mont t (Mm^3) must be greater than to equal to the dead storage (DS) volume and less than or equal to full storage (FS) volume.

$$DS \leq S_t \leq FS \qquad t = 1,2,\ldots\ldots 12 \qquad (17)$$

h) Crop diversification constraint

Since the command area lies in a region which predominantly dependson agricultural economy, the planners want to ensure production of certain cash crops in addition to essential crops. The targets are based on the existing cropping pattern and food requirements of the people in the command area etc (Directorate of Economics and Statistics, 1992).

$$A_i \geq A_{i\text{-min}} \qquad (18)$$

$$A_i \geq A_{i\text{-max}} \qquad (19)$$

The other constraints incorporated in the model are crop production targets, downstream requirements, labour and fertiliser availability etc (Srinivasa Raju, 1995). Cost coefficients, crop yields and other input parameters are obtained from Sri Ram sagar Project reports but are not presented here due to space limitations.

In the planning model, stochastic nature of inflows are considered through chance constrained programming. The monthly inflows into Sri Ram Sagar reservoir are assumed to follow the og-normal distribution. Twenty three years of historical inflow data is used to obtain the inflows at various dependability levels. Table 2 presents the inflows from June to December for various dependability levels. the inflows of other months are not significant and are neglected. When inflows at 50% dependability level are considered it is found that the demands are less than the available inflows (all the demands will be met from the available inflows). Inflows at four dependable levels i.e., 75% (general planning level for water resources projects in India), 80%, 85%, 90% (by considering the dought scenario as suggested by Maji and Heady (1980) are considered for the present analysis.

Table 2

Inflows into SRSP at various dependability levels (Mm^3)

	Dependability Levels			
Months	90%	85%	80%	75%
Jun	132.10	161.60	190.00	218.19
July	372.88	460.57	545.77	630.94
Aug	798.50	987.46	1171.2	1355.2
Sep	812.70	1011.4	1205.8	1401.3
Oct	352.02	443.85	534.76	627.05
Nov	56.900	78.070	100.67	125.11
Dec	36.000	44.430	52.320	60.150
Total	2561.50	3187.49	3800.70	4417.99

Results and discussion

Optimization of objective function is perfomed with a linear Programming (LP) algorithm. Results are presented in Table 3 for inflows at 90% 85% 80% and 75% dependable levels. It is observed that for 90% dependability level, Paddy(s) and Paddy(w) occupied 62,930 ha and 14,700 ha respectively.

The acreage of Groundnut(s), Groundnut(srf), Groundnut(w) are 1,500 ha, 93,260 ha, 15810 ha. The acreages of Chillies and Sugarcane are 3,100 ha and 4,100 ha respectively. Total irrigated area is 1,81,590 ha (101.96% irrigation intensity) whereas total cropped area is 2,74,860 ha (154.33% cropping intensity). The optimum cropping pattern yields net benefits of 1,672.9 million Rupees.

Table 3
Cropping Pattern from the Planning Model

Crops and related Parameters	Units	Solution for maximization of net benefits at Dependability Levels			
		90%	85%	80%	75%
1. Paddy (s)	1000ha	62.93	62.93	62.93	119.04
2. Maize (s)	1000ha	5.000	5.000	5.000	5.000
3. Sorghum (s)	1000ha	1.900	1.900	1.900	1.900
4. Groundnut (s)	1000ha	1.500	1.500	62.85	38.66
5 Vegetables (s)	1000ha	2.100	2.100	2.100	2.100
6. Pulses (s)	1000ha	4.200	4.200	4.200	4.200
7. Paddy (srf)	1000ha	0.000	0.000	0.000	0.000
8. Groundnut (srf)	1000ha	93.26	93.26	31.92	0.000
9. Paddy (w)	1000ha	14.70	14.70	14.70	14.70
10.Groundnut (w)	1000ha	15.81	66.18	97.15	97.15
11. Pulses (w)	1000ha	39.85	39.85	39.85	39.85
12. Maize (w)	1000ha	13.00	13.00	13.00	13.00
13. Sorghum (w)	1000ha	4.500	4.500	4.500	4.500
14. Vegetables(w)	1000ha	1.700	1.700	1.700	1.700
15. Chillies (ts)	1000ha	3.100	3.100	3.100	3.100
16 . Sugarcane(ts)	1000ha	4.100	4.100	4.100	4.100
Irrigation Intensity	%	101.96	130.24	182.08	200.00
Cropping Intensity	%	154.33	182.61	200.00	200.00
Fertilizer application	1000 Ton	36.810	41.870	44.960	50.010
Net Benefits (Million Rupees)		1672.9	2189.0	2657.0	2824.0

Tables 4 and 5 present ground water and surface water allocation policies. It is observed from Table 4 that ground water is fully utilized and is particularly useful in the months of February to June when there is less water in the reservoir and its contribution is nil from July when there is sufficient surface water to cater to the demands. It is observed from Tables 4 and 5 that conjunctive use of surface and ground water helps to maintain timely crop schedule.

Table 4
Ground water allocation policies (Mm^3)

Months	Solution for Maximization of Net Benefits at Dependability Levels			
	90%	85%	80%	75%
Jan	0.0000	0.0000	0.0000	0.0000
Feb	98.770	40.550	7.6400	0.0000
Mar	143.06	221.45	269.65	177.40
Apr	22.500	22.500	22.500	22.500
May	21.420	21.420	21.420	21.420
Jun	111.76	91.600	76.310	176.20
Jul	0.0000	0.0000	0.0000	0.0000
Aug	0.0000	0.0000	0.0000	0.0000
Sep	0.0000	0.0000	0.0000	0.0000
Oct	0.0000	0.0000	0.0000	0.0000
Nov	0.0000	0.0000	0.0000	0.0000
Dec	0.0000	0.0000	0.0000	0.0000
Total	397.51	397.51	397.51	397.51

Table 5
Surface water allocation policies (Mm^3)

Months	Solution for Maximization of Net Benefits at Dependability Levels			
	90%	85%	80%	75%
Jan	310.57	475.93	577.60	577.60
Feb	184.83	421.61	564.30	571.94
Mar	63.580	98.420	119.84	212.09
Apr	10.000	10.000	10.000	10.000
May	9.5100	9.5100	9.5100	9.5100
Jun	49.670	69.840	98.240	126.43
Jul	161.52	161.52	187.90	313.33
Aug	195.13	195.13	265.81	396.78
Sep	213.84	213.84	302.67	442.70
Oct	121.62	121.62	150.82	235.81
Nov	82.220	106.14	120.86	120.86
Dec	225.39	310.91	363.50	363.50
Total	1627.87	2194.47	2771.06	3380.56

Sensitivity analysis

Sensitivity analysis of inflows at different dependability levels are also studied to assess the possible optimum cropping pattern. These are also presented in Table 3. It is observed that there is no change in crop acreage of Maize (s&w), Sorghum (s&w), Vegetables (s&w), Pulses (s&w), Paddy (w), Paddy (srf), Chillies (ts) and Sugarcane (ts) at all four dependability levels. In case of Paddy (s) constant acrege is observed from 90% to 80% dependability levels and it increased to 1,19,040 ha at 75% dependability level.

It is also observed that Groundnut(w) increased from 15,810 to 97,150 ha (90% level to 80% level) and there after it remained constant. It is observed that as dependability decreases (from 90% to 75%) net benefits are increasing. Irrigation intensity has reached 200% at 75% dependability level indicating that same land can be irrigated twice. Similarly net benefits at 75% dependability level are 2,824 million rupees and are 68.8% more than those at 90% dependability level. It is observed that the ground water is fully utilized (397.51 Mm^3) in all the four cases even through the amounts utilized in individual months are different. Ground water is utilized to meet 19.62%, 15.33%, 12.54%, 10.52% of irrigation demands for 90%, 85%, 80% and 75% dependability levels respectively. Remaining irrigation demand is catered to by surface water. It is observed from Tables 4 and 5 that there is constant ground water pumping of 22.50 and 21.42 Mm^3 for Sugarcane in the months of April and May for all the four inflow levels. Similar trend is observed in the months of April and May for all the four inflow levels. Similar trend is observed in the months of April and May for surface water allocations. Comparison of the results indicated that the methodology is quite versatile and can be used in other similar situations, as well, with suitable modifications.

Conclusions

Based on the analysis of the results of a real world irrigation planning problem of Sri Ram Sagar Project, Andhra Pradesh, India, the following conclusions are drawn.

(i) Optimum irrigation plan for 90% dependability level (net benefits 1,672.9 million rupees and irrigation intensity 101.96%) can be implemented in the study region for drought scenario.

(ii) Optimum irrigation plan for 75% dependability level (net benefits 2,824 million rupees and irrigation intensity 200%) can be implemented inthe study region as for general planning level for water resources projects.

(iii) Net benefits at 75% dependability level are increased by 68.8% as compared to 90% depnedability level.

(iv) Conjuctive use of surface and ground water is praciticularly found to be useful when there is little or no rainfall.

(v) Comparison of the results indicate that the methodologies are quite versatile and can be used in other similar situations, as well, with modifications.

References

1. Direcorate of Economics and Statistics., 1992, Statistical abstracts of Andhra Pradesh, Government of Andhra Pradesh.

2. Garg. N.K. and Ali, A., 1998. Two level optimization model for lower indus basin,Agricultural Water Management, Vol. 36(1), pp. 1-20.

3. Lakshminarayana, V. And Rajagopalan, S.P. 1997. Optimal cropping pattern for basin in India,

   Journal or Irrigation and Drainage Engineering ASCE, Vol 103, pp.53-70.

4. Loucks, D.P., Stendinger, J.R. and Haith, D.A. 1981. Water Resources Systems Planning and Analysis, Prentice-Hall,Englewood Clifts, New Jersey.

5. Maji, C.C. and Heady, E.O., 1980. Optimal resources Bulletin, Vol.16(3), pp. 438-443.

6. Pawar, P.K. and Murthy, J.S.R., 1991. District level crop water demand, National Seminar on use of Computers in Hydrology and water Resources, Central Watwer Commission, New Delhi, pp.3-106 to 3-118.

7. Srinivasa Raju, K., 1985. Studies on Multicriterion Decision Making Methods and Management of Irrigation Systems. Phd thesis,Indian Institute of technology, Kharagpur.

8. Tandaveswa, B.S., Srinivasan, K., Amarendra Babu, N., and Remash, S.K. (1992). Modeling an over developed irrigation system in south India, International Journal of Water Resources Development, Vol.8 (1), pp.17-29.