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Cropping pattern optimization for Chamravattom regulator-cum-bridge using linear programming problems

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Abstract
In India, land and water resources management is considered with utmost strategic priority. Management of these natural resources is also one of the main aspects in the financial development of the country. Therefore optimum usages of such available resources using different optimization techniques become very important. The aim of this work is to determine an optimal cropping pattern to maximize the net profit for the command area of the Regulator-Cum-Bridge (RCB) at Chamravattom in Malappuram district, Kerala. The optimal cropping pattern was suggested by using Linear Programming Model (LPP) which was developed on a seasonal basis for Kharif, Rabi and summer and solved using LINDO software. The optimal solution was determined by analyzing the B/C ratio under different cases for a particular season. Sensitivity analysis was also performed to find whether the solutions obtained are optimal. The study summarizes that optimal operational policies, even for small water resource projects, increase the economical viability to a great extent and make the project more socially acceptable.

Keywords: Cropping pattern, optimization, linear programming etc.

1. Introduction
In India due to the rapid change in population and urbanization, land and water resources are becoming very limited. Land and water are the key factors for the sustainable agricultural development of a nation. Management of this land and water resources is also one of the main financial development. Hence there is necessity of implementation of techniques in optimum usage of such available resources. Kerala is often considered as the land of water. Still the state experiences severe shortage of water for domestic, irrigation and hydro power generation during the summer months. The rivers hardly contain any water during six months in a year. Compared to national average, Kerala receives 2.78 times more rainfall, but due to steep sloping and undulating topography rain water is not much retained on land. At the same time, unit land of Kerala has to support 3.6 times more population when compared to national level scenario. Hence for self-sufficiency unit land of Kerala has to produce 3.6 times drinking water, food, biomass and associated water requirement compared to national average. Proper management of land and water resources of Kerala would certainly make the situation more comfortable than today. Crop optimization has received extensive attention in recent years and different mathematical models have been developed to determine the optimal use of the available resources for maximizing the net benefits subjected to some constraints. Reservoirs are the most important elements of complex water resources development system. The main objectives while operating multipurpose reservoirs include the determination of optimum water storage for meeting drinking and irrigation purposes and also preventing the saline water intrusion. Hence optimal cropping pattern becomes a critical deciding factor for which the reservoir operation plan has to be formulated properly. Irrigation consumes a huge quantity of water and quite naturally the major allocation from a reservoir system goes for irrigation. Hence, our aim should be to increase the effectiveness of every drop of water used for irrigation and to prepare best optimal cropping pattern to achieve the maximum benefits.
This study was undertaken to optimize the cropping pattern for the regulator cum bridge (RCB) across Bharathapuzha River at a place locally known as Chamravattom using Linear Programming Model (LPP) for maximization of net economic profit.

2. Material and Methods

2.1 Study Area

Bharathapuzha River, the second longest river of the state (Kerala) takes its origin at an elevation of +1964 m above M.S.L. from Anamalai hills and flows through the districts of Coimbatore, Palakkad, Malappuram and Thrissur, and joins the Arabian Sea near the Ponnani town, where it is known as Ponnanipuzha. The length of the Bharathapuzha River is 209 km with a catchment area of 6186 sq. km. The catchment area spread over 11 taluks from the Western Ghats to the Arabian Sea. About 2/3rd of the drainage area of the basin i.e., 4400 sq. km. lies in Kerala State and the balance in Tamil Nadu. The Chamravattom RCB is about 6 km upstream of the confluence point of the river and sea. Thirunavaya, the historically important place for the only Brahma temple in South India and the Mamanga festival is situated on the right bank of the RCB. The latitude and longitude of the site are 10º 51' North and 75º 57' East.

2.2 LP Model formulation

An irrigation planning and operation model involves the development of methods for estimating which crops should be grown within an irrigation area and the area to be cultivated under each crop. The model provides a systematic means of estimating the farm income and expense budget and also helps to optimize the resource allocation. The mathematical model involves identification of the decision variables, the constraints and the objective function, which is to be maximized or minimized. Two basic assumptions were considered in this study while formulating the problems which are as follows:

1. All inputs other than water, namely seeds, fertilizers, weedicides and pesticides of desired quality are available in adequate quantities
2. Gross irrigation efficiency is taken as 57%.

A linear programming model is formulated to suggest the optimal cropping pattern to find out maximum net benefit at different combinations of area under different crops. The objective function of the model is subject to the two constraints that are total water available for irrigation in kth season and total area available for cultivation in any season is 18,560 ha. Mathematical form of objective function and constraint is expressed as follow.

2.3 Objective function: Maximize net economic profit

$$\text{Max } Z = \sum_{j=1}^{n} Pj \; {*}Xj$$

2.4 Constrains on water available for irrigation and area available for cultivation

$$\sum_{j=1}^{n} Xj \; {*}Qkj \quad \leq Qk$$

Where, Z is the net benefit from the command area to be maximized, Xj is the area under jth crop and Pj is the net return from jth crop per hectare. Qk is the total available surface water in kth season, Qkj is the quantity of water required for irrigating jth crop in kth season, n is the number of crops considered in a particular season.

Two boundary conditions considered during the formulating the model are given below:

1. Lower and upper bounds are given for any particular crop as desired by the decision makers.
2. Lower and upper bounds given for the total area under cultivation in each season.

The area constraints are taken randomly based on the present area under cultivation for kharif, rabi and summer seasons. Area allotted for different crops in ha denoted as:

Paddy nursery	:	X1	Paddy puddling	:	X2
Paddy main field	:	X3	Coconut	:	X4
Coconut + Pepper + Arecanut	:	X5	Pepper + Arecanut	:	X6
Coconut + Banana + Vegetables	:	X7	Banana	:	X8
Vegetables	:	X9			

The area constraints are the same for kharif and Rabi seasons except the third constraint. The third constraint was taken as X3 ≥2745. The model was run with the above values and the results obtained were analyzed.

Table 1: Various cases of area constraints for Kharif, Rabi and Sumer cropping season

Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
X1 = 0.1X3	X1 = 0.1X3	X1 = 0.1X3	X1 = 0.1X3	X1 = 0.1X3	X1 = 0.1X3
X2 = 0	X2 = 0	X2 = 0	X2=0	X2 = 0	X2 = 0
X3 ≥ 1200	X3 ≥ 1200	X3 ≥ 1200	No lower limit	X3 ≥ 1200	X3 ≥ 1200
X4 ≥ 200	X4 ≥ 200	X4 ≥ 200	X4 ≥ 200	X4 ≥ 200	X4 ≥ 200
X5 ≥ 140	X5 ≥ 140	X5 ≥ 140	X5 ≥ 140	X5 ≥ 140	X5 ≥ 140
X6 ≥ 10	X6 ≥ 10	X6 ≥ 10	X6 ≥ 10	X6 ≥ 10	X6 ≥ 10
X7 ≥ 50	X7 ≥ 50	X7 ≥ 50	X7 ≥ 50	X7 ≥ 50	X7 ≥ 50
X8 ≥ 50	X8 ≥ 50	X8 ≥ 50	X8 ≥ 50	X8 ≥ 50	X8 ≥ 50
X9 ≥ 100	X9 ≥ 100	No lower limit	X9 ≥ 100	X9 ≥ 100	X9 ≥ 100
X3 ≤ 3641	X3 ≤ 3641	X3 ≤ 3641	X3 ≤ 3641	X3 ≤ 3641	X3 ≤ 3641
X5 ≤ 6120	X5 ≤ 6120	X5 ≤ 6120	X5 ≤ 6120	X5 ≤ 6120	X5 ≤ 6120
X6 ≤ 100	X6 ≤ 100	X6 ≤ 100	X6 ≤ 100	X6 ≤ 100	X6 ≤ 100
X7 ≤ 600	X7 ≤ 600	X7 ≤ 600	X7 ≤ 600	X7 ≤ 600	No upper limit
X8 ≤ 1200	No upper limit	X8 ≤ 1200	X8 ≤ 1200	X8 ≤ 1200	X8 ≤ 1200
X9 ≤ 250	X9 ≤ 250	X9 ≤ 250	X9 ≤ 250	No upper limit	X9 ≤ 250
			X4 ≤ 1500		

The benefit-cost (B/C) ratio for all the cases are calculated as

B/C ratio = (Net benefit from the given crops)/ (total cost of production of the crops).

Sensitivity analysis was also done to determine the variation in net profit with fluctuations in the market price. It indicates the changes in the model output resulting from the changes in the model component, the input or the parameters. It also shows the rate of change in one factor with respect to change in another factor.

3. Results and Discussions

3.1 Irrigation Requirement

Irrigation requirement of the command area was obtained by estimating the crop water requirement and then deducting the effective rainfall from that. Crop water requirement for different crops were computed using Modified Penman method. Effective rainfall was taken as 75% of the 75% chance rainfall. Calculated season wise crop water requirement for crops cultivated under command area is given in the table 2.

Table 2: Season wise irrigation water requirement of crops cultivated in command area

	Crops	Irrigation Water Requirement (m^3/ha)		
		Kharif	Rabi	Summer
1.	Paddy nursery	1508.25	509	2641
2.	Paddy puddling	0.07	0.04	0.07
3.	Paddy main field	2800.49	7062.69	10306.95
4.	Coconut	510	1288.5	5019.75
5.	Coconut + Pepper + Arecanut	970.5	2036.8	7737.5
6.	Pepper + Arecanut	786	1716.1	6572.75
7.	Coconut + Banana + Vegetables	0	1295.8	5086.4
8.	Banana	687.60	1545.06	5951.55
9.	Vegetables	0	0	3916.81

3.2 Optimization of cropping patter

Monthly optimal water available for irrigation was used for obtaining optimum cropping pattern for the command area of the project. For each of the three seasons, six cases were considered with set of different constraints as described in Table 1. The solution to the linear programming model was obtained using the software package-LINDO. The trials were conducted with an irrigation efficiency of 57%. Results obtained for six cases after analysis is presented in the following table with their BC ratios and maximum net profit.

Table 3: BC ratio and net profit obtained for six cases for Kharif, Rabi and Summer season

	Kharif		Rabi		Summer	
	BC Ratio	Net Profit	BC Ratio	Net Profit	BC Ratio	Net Profit
Case-1	2.36	1054638000	2.01	798741100	2.36	1054638000
Case-2	1.78	1441681000	1.6	848672800	1.79	1441681000
Case-3	2.36	1054638000	2.08	798741100	2.37	1056860000
Case-4	2.10	810529800	2.09	808814300	2.07	810529000
Case-5	2.36	1054638000	1.6	848670000	2.36	1054638000
Case-6	1.76	2005095000	1.75	1494366000	1.76	2005095000

Among the different optimizations, for the kharif season the highest B/C ratio (2.36) with maximum net profit of about Rs. 105.46 crores was obtained for cases 1,3 & 5, of which case 3 is considered as a optimal solution because as per case -3 maximum area was allocated to coconut crop. Since, coconut is a perennial crop, effort is required only during the initial stages and maintenance required in minimal when compared to other crops. For Rabi season case-4 is considered as optimal solution as it was showing the highest B/C ratio (2.09) and net maximum profit of about Rs.80.8814 crores. Similarly for summer season case- 3 considered as optimal solution with highest BC ratio (2.37) with maximum net return of about Rs. 105.686 crores. After analysis, among the six different cases of areas under different crops, optimized cropping pattern suggested by the LPP model to achieve maximum profit for Kharif, Rabi and summer season is summarized in the table 4.

Table 4: Optimized cropping pattern suggested for maximum profit for Kharif, Rabi and Summer season

Crops	Kharif season		Rabi season		Summer season	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
Paddy nursery (X1)	120	2.36	268.79	2.09	120	2.37
Paddy main field (X3)	1200		2687.9		1200	
Coconut (X4)	9340		1500		9340	
Coconut + Pepper + Arecanut (X5)	6120		6120		6120	
Pepper + Arecanut (X6)	100		100		100	
Coconut + Banana + Vegetables (X7)	600		600		600	
Banana (X8)	1200		1200		1200	
Vegetables (X9)	0		250		0	
Total	Rs.1054638000		Rs.808814300		Rs.1056860000	

4. Conclusion

A linear programming model is formulated to find out optimal land allocations for different crops to achieve maximum net profit for three cropping seasons under the command area of the Regulator-Cum-Bridge (RCB) at Chamravattom in Malappuram district, Kerala. Based on the study carried out, the following conclusions are made:

1. The evapotranspiration rates for different months were calculated using Modified Penman method. The highest ET of 5.5 mm/day was found for the month of March.
2. Optimal cropping pattern with net benefit maximization gave a net benefit of about Rs 105.46 crores for Kharif and Summer seasons and about Rs 80.8814 crores for Rabi season.
3. The study summarizes that optimal operational policies, even for small water resource projects, increase the economical viability to a great extent and make the project more socially acceptable. Hence, all reservoirs must be planned based on optimal operational policies incorporating maximum number of objectives to improve their utility value and better social acceptance.

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