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Optimal Crop Planning for Retamunda Branch Canal System under Uncertainty of Canal Release

N. PANIGRAHY[1], A. K. MOHANTY, S. MOHAPATRA and S. LENKA
AICRP on Water Management, RRTTS, Chiplima - 768 025, Odisha

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Improvement of water productivity of the canal commands through structural interventions requires huge investment. This paper describes nonstructural interventions through development of optimal crop planning in the Retamunda Branch Canal System, a tail end branch canal of the Hirakud Command, in the western part of Odisha. Considering four scenarios with different objectives, the optimal cropping patterns under the commands of individual distributaries have been worked out, using linear programming, so that improvement in irrigation efficiency, in terms of water productivity, could be feasible. Among various scenarios, the cropping pattern obtained under Scenario – II, with the objective to utilize the maximum area for cultivation along with the constraint of water availability for each outlet was found to be feasible for optimal land and water utilization and generation of requisite employment. The optimal cropping patter due to uncertainty of water availability for irrigation was analyzed at 90%, 75% and 60% of the present release. It was observed that with the decrease in canal release up to 10%, 25% and 40%, it is possible to obtain about 97%, 93% and 87% of the net return per unit area that is obtained with 100% of canal release under Scenario – II. However, it is not feasible to plan at least 1/3rd of the command area under heavy duty crops with the decrease in canal release beyond 10%.

(***Keywords:*** *Cropping Pattern, Optimization, Deficit-Surplus Analysis, Linear Programming*)

Irrigation has been given top priority for economic development of India. Due to huge investments made for development of this sector after the independence, the country's irrigation covered crop area has increased to 58.13 million hectares in 2011 from 22.6 million hectares in 1951. However, out of the total arable land of 160 million hectares only about 35% of total agricultural land in India was reliably irrigated in 2010. The reasons are manifold – low overall irrigation efficiency in canal irrigation, improper crop selection, inadequate storage in the reservoirs due to various reasons, increased demand for non-agricultural use of water, etc.

The allocation of water for irrigation in a multipurpose reservoir can be affected by change in inflows to the reservoir and outflow demands from it. The inflows to most of the large reservoirs are susceptible to change due to changes in rainfall pattern in the catchment (IPCC, 2007), land use changes in the upper catchment, construction small and medium water harvesting structures in the upstream. Further, the demands of water for domestic and industrial uses keep on increasing due to increase in population and industrialization, both in the upstream and downstream of a reservoir. Therefore, to maintain the irrigation potential of an irrigation project, the cropping pattern in the command area should be worked out periodically based on water allocation for irrigation.

To overcome the difficulties of attaining and maintaining the potential, both structural and non-structural interventions are needed. The structural interventions which include construction of control structures, lining of canals, etc., involve huge cost and time for implementation. Further, the scope for modification of the structures according to the change in water available for irrigation e.g., due climatic uncertainty, is limited. On the other hand, non-structural interventions that involve only managerial measures can be handy and adoptable with a fraction of the cost of the former. For proper management the managers of irrigation water should be equipped with scientific tools of proven credibility. Optimization of cropping pattern with the constraints of land and water availability is one such tool.

With the availability powerful computing facilities, quite a few optimization models for land and water have been developed and now-a-days commonly used by irrigation policy makers. An optimization model requires an objective function and one or more constraints, expressed in mathematical form. In agriculture, both the objective function and the constraints can be expressed in

**Corresponding Author :* Email: n.panigrahy@gmail.com

linear algebraic equations. Hence, linear programming is one of the best tools for optimal allocation of land and water resources (Panda *et al.*, 1985). Many studies on optimization of irrigation water resources using linear objective functions have been carried out to maximize the net benefits while selecting an optimum cropping pattern and conjunctive use studies (Maurya, 2013; Mani and Singh, 2009; Sethi *et al.,* 2002; Singh *et al.,* 2001; Paul *et al*., 2000; Vedula and Nagesh Kumar, 1996,).

Hirakud canal irrigation system of Hirakud multipurpose reservoir project in the state of Odisha provides irrigation up to 1,59,100 ha in *Kharif* and 1,06,820 ha in seasons respectively (Govt. of Orissa, 2007). It is affected by low water productivity, with paddy being the major crop in both *Kharif* and *Rabi* seasons. Although the productivity of rice in the region is not very encouraging, at 2.05 t ha^{-1} (Govt. of Odisha, 2013), the farmers are inclined towards the crop. It has been estimated that the mean annual deficit of irrigation water amounts to around 1956 million cubic metres (MCM) which is mainly due to extensive rice cultivation in the monsoon and non-monsoon (Raul *et al.*, 2008). There has been a decrease in annual inflow, from 37000 MCM to about 27000 MCM, as well as in monsoon inflow into the reservoir, from 32700 MCM to 28800 MCM during 1958 to 2008. The average loss of gross, live and dead storages was computed to be 0.64%, 0.41% and 1.22% per annum respectively (Govt. of Orissa, 2007). The demand water for industrial use is increasing with time. Hence, the availability of water for agricultural use is reducing day by day, leading to conflict among water users of the multipurpose project (Choudhury *et al.,* 2012).

Keeping these in view, the current study was conducted with various scenario analyses for optimal crop planning, along with canal release uncertainties, in a tail end branch canal system of Hirakud command area using linear programming model.

MATERIALS AND METHODS

Study area

The Hirakud canal command area falling under the Western Central Table Land agro-climatic zone of Odisha is situated between 20^{o} 43′ to 21^{o} 41′ N latitude and 82^{o} 39′ to 83^{o} 58′ E longitude. Surface irrigation is provided to the command through three canal distribution systems, namely, Bargarh main canal, Sason main canal and Sambalpur distributary. Bargarh main canal takes off from right dyke of Hirakud Dam (84.28 km in length) with 108.16 cumecs discharge and irrigates 1,30,255 ha. The present study has been undertaken in the command area of Retamunda Branch Canal, which takes off from the right of Bargarh main canal at 64.925 km reduced distance (RD) having five distributaries (Table 1). Plain undulating topography prevails in the command of the distributary with average slopes varying between 1 and 6%. Average annual rainfall of about 1250 mm is experienced in the area with the annual temperature variation of 10^{o}C to 45^{o}C. The soil varies between light to medium texture and red soils to heavy textured calcareous soils (Sahu and Mishra, 2005). The physical properties of aquifers show high spatial variability with hydraulic conductivity varying from 0.5 to 3 m day^{-1}(CGWB, 1998) with the groundwater table fluctuating from 1.5 to 6 m. Baring the month of May and periodical closure for 30 days in the month of November and December for maintenance, the canal runs rest of the months. Paddy is the predominant crop cultivated both in monsoon and non-monsoon seasons.

Deficit-surplus analysis

The study focused on assessment of the water availability at different reaches of the canal system; water demand for the crops grown at different reaches; estimation of gap in the demand and supply; and devising intervention to minimize the demand – supply gap. The canal release is continuous for the cropping period (approximately 100 days) except the closure, for minor

Table 1. *Details of outlets from the Retamunda branch canal system*

Sl. No.	RD* (km)	Distributary/ Minor/ Sub Minor Name	Bed Level (m)	Discharge (cumec)	Length (km)	Area (ha)
1	1.722	Bahubasa Disty	169.243	0.283	3.124	367.46
2	3.474	Beheramal Disty	169.56	0.368	3.581	498.68
3	3.932	Salhepali Disty	168.868	1.160	7.924	1445.58
4	9.068	Sukha Disty168.365	7.107	11.574	6645.51	
5	9.068	Kebar Disty168.579	3.482	22.021	2315.28	

*RD - Reduced distance

Table 2. Details of crop parameters used in the analysis

Crop Type	Crops	Water Requirement* (cm)	Net Return (Rs ha^{-1})
Heavy	Paddy, Sugarcane	100	25,000
Medium	Groundnut, Wheat, Vegetables	50	22,500
Low	Blackgram, Greengram, Pea, Mustard	30	16,000

*The total water requirement for the entire cropping period

maintenance for 3 days. The water availability at each outlet (distributary) was calculated from their discharge rate. The crops grown in the command area were divided into 3 groups *viz*., heavy, medium and low. The average parameters considered for analysis of different crops are presented in the Table 2.

The total crop water requirement for the command of each outlet is calculated using the following expression :

$$WR_i = A^i_H \text{ x } D_H + A^i_H \text{ x } D_M + A^i_L \text{ x } D_L$$

where, WR_i is the total water requirement for the command area of outlet 'i' (ha cm), A^i_H, A^i_M and A^i_L are the area under heavy, medium and low duty crops in the command area of outlet 'i' respectively (ha), and D_H, D_M and D_L are the total depth of water required for the heavy, medium and low duty crops respectively (cm).

The water available for each outlet is calculated considering the discharge and the duration of canal opening. The following formula was used.

$$WA_i = q_i \text{ x } 36 \text{ x } 24 \text{ x } N$$

where, WA_i is the total water available at outlet 'i'(ha cm),q_i is the discharge of outlet 'i' (cumec) and N is the number of operation of the canal.

The water available at each outlet is compared with its crop water requirement in the same command area and deficit surplus analysis is carried out. If $WR_i > WA_i$ then the outlet is operating under deficit condition, if $WR_i < WA_i$ then the outlet is operating under surplus condition and if $WR_i = WA_i$ then the outlet is operating under optimal condition.

Optimal allocation of crops

If an outlet is not operating under optimal condition, proper crop planning is required for the outlet. For optimal crop planning in the command area of the outlet, four frequently observed scenarios are considered. The details of the scenarios and their methodology are presented below.

Scenario – I

Under this scenario, the main objective is to minimize the surplus water available at the outlet with the constraint that the total area under all the type of crops should be less than or equal to the designed culturable command area of the outlet. Mathematically it is expressed as:

Objective : $\text{Min: } Z_i = WR_i - WA_i$

Constraints : $A^i_H + A^i_M + A^i_L \leq CCA^i$

$$A^i_H, A^i_M, A^i_L \geq 0$$

where, Z_i is the objective function, WR_i and WA_i are the water requirement in the command area and water available at the outlet 'i' respectively; A^i_H, A^i_M and A^i_L are the area under heavy, medium and low duty crops in the command area of outlet 'i' respectively; and CCA^i is the designed culturable command area of the outlet 'i'.

Scenario – II

Under this scenario, the main objective is to utilize the maximum area for cultivation with the constraint of water availability for each outlet. Mathematically it is expressed as:

Objective : $\text{Max: } Z_i = A^i_H + A^i_M + A^i_L$

Constraints : $A^i_H \times D_H + A^i_M \times D_M + A^i_L \times D_L \leq WA_i$

$$A^i_H + A^i_M + A^i_L \leq CCA^i$$

$$A^i_H, A^i_M, A^i_L \geq 0$$

where, D_H, D_M and D_L are the total depth of water required for the heavy, medium and low duty crops respectively (cm).

Scenario – III

Under this scenario, the main objective is to maximize the net returns from the command area with the constraints (1) water availability for each outlet should meet the demand, and (2) at least 1/3rd of the cropped area should be paddy (heavy duty crop) as per choice of the people. Mathematically it is expressed as :

$$\text{Objective} \quad : \text{Max}: Z_i = A^i_H + A^i_M + A^i_L$$

$$\text{Constraints}: A^i_H \times D_H + A^i_M \times D_M + A^i_L \times D_L \leq WA_i$$

$$A^i_H \leq CCA^i_A/3$$

$$A^i_H + A^i_M + A^i_L \leq CCA^i$$

$$A^i_H, A^i_M, A^i_L \geq 0$$

Scenario – IV

Under this scenario, the main objective is to maximize the net agricultural return from the command area of each outlet. The constraints here are, (1) water availability for each outlet should meet the demand, and (2) the total area under cultivation should be less than or equal to the available area. Mathematically it is expressed as:

$$\text{Objective} \quad : \text{Max}: Z_i = NR_H \times A^i_H + NR_M \times A^i_M + NR_L \times A^i_L$$

$$\text{Constraints}: A^i_H \times D_H + A^i_M \times D_M + A^i_L \times D_L \leq WA_i$$

$$A^i_H + A^i_M + A^i_L = CCA^i$$

$$A^i_H, A^i_M, A^i_L \geq 0$$

where, NR_H, NR_M and NR_L are the net return per hectare from heavy, medium and light duty crops respectively, and the other terms are same as defined above.

Uncertainty of canal release

Since the optimal cropping pattern is sensitive to resource (land and water) availability it would be different when the limits of the resources are changed. While the CCA is not expected to change much, the release of canal water for irrigation may be different due to many factors, including climate change. Assuming the present release of irrigation water at the outlets at 100%, the change in the optimal cropping pattern under different scenarios at 90%, 75% and 60% of the canal releases were carried out using the above methodology.

RESULTS AND DISCUSSION

Deficit-surplus analysis

The analysis of data was carried by the above mentioned methodology. The results obtained along with discussions are presented below. Since rice is grown almost entirely in the command area, only heavy duty crop was considered for analyzing the deficit surplus analysis. The status of the distributaries is presented in Table 3. Deficit status was observed for all the distributaries except Kebar distributary. The water deficit is attributed because of growing heavy duty crops in the command areas of the individual distributaries. It is estimated that about 11% of the command area would remain unirrigated if rice is required to be grown in the entire command area.

Scenario analysis

The optimal allocations of areas under different types of crops under all the scenarios were computed using the above methodology for each outlet and the total system. It was observed that about 98% of the total command area can be irrigated to maintain the optimality of water use (Scenario - I). However, there would be surplus water in the command area of Kebar distributary even if the entire CCA is cultivated with heavy duty crops. The results revealed that 100% of command area of the system can be irrigated, if the designed cropping pattern under Scenario – II could be followed. Though the total command area can be provided irrigation under this scenario, there would be marginally reduced average rate of net return per hectare of the irrigated area compared to the previous scenario. It is observed that the cropping pattern obtained under Scenario – III would give more net return than that of the first two scenarios, with provision of irrigation for 100% of the CCA with increased average rate of net return per hectare. The optimal allocation of areas under different types of crops under Scenario – IV suggests that for maximum net return from the command area, with 100% land utilization, no low duty crop may be taken. The summary of the scenario analysis is presented in Table 4 and Fig. 1.

Table 3. *Deficit - surplus analysis of the Retamunda branch canal*

Sl. No.	Distributary	CCA*	Water Status			Actual	Net return	
		(ha)	WR(ha-cm)	WA(ha-cm)	Status	area (ha)	(Rs)	(Rs ha^{-1})
1	Bahubasa Disty	367.46	36746	24451	Deficit	245	6112800	16635
2	Beheramal Disty	498.68	49868	31795	Deficit	318	7948800	15940
3	Salhepali Disty	1445.58	144558	100224	Deficit	1002	25056000	17333
4	Sukha Disty	6645.51	664551	614045	Deficit	6140	153511200	23100
5	Kebar Disty	2315.28	231528	300845	Surplus	2315	57882000	25000
	Total	11272.51	1127251	1071360	Deficit	10020	250510800	22223

*CCA - Culturable command area

Table 4. *Summary of scenario analysis*

Scenario	Cropping pattern (ha)					% CCA cultivated	Net Return (Rs)	Net Return (Rs ha^{-1})
	Heavy	Medium	Low	Uncultivated	Total			
Scenario - I	9114.86	1596.72	357.36	203.56	11068.94	98.19	269515578	24349
Scenario - II	8860.89	2180.29	231.33	0.00	11272.51	100.00	274280039	24332
Scenario - III	8798.28	2399.42	74.81	0.00	11272.51	100.00	275140887	24408
Scenario - IV	8768.35	2504.16	0.00	0.00	11272.51	100.00	275552401	24445

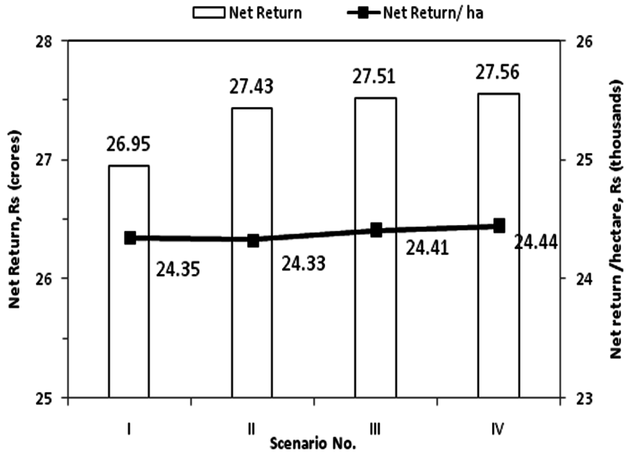

Fig. 1. *Net return and net return per unit area under different scenarios*

Uncertainty of canal release

Optimization of cropping pattern under the scenarios II, III and IV were carried out with reduced water availabilities of 90% 75% and 60% of the present values to assess their feasibility and adoptability. The results are presented in Table 5. As revealed in the table it is feasible to achieve 100% land utilization in the command area under the conditions of decreased water availability in scenarios - II and IV only, because of no limitation on reducing the area under heavy duty crops, which is imposed as a constraint in Scenario - III.

The distributary wise deficit-surplus analysis of canal water in the command area of Retamunda Branch Canal for *Rabi* season depicts that all the outlets are operating under sub-optimal conditions. As a measure of non-structural intervention, to minimize the demand-supply gap, optimal cropping pattern under four different scenarios for each outlet were determined. All the outlets of the system can be operated optimally with the adoption of the designed cropping pattern in the command areas of the distributaries except for the Kebar distributary. Further, it is observed that it is feasible to provide irrigation to the entire command area even if the canal releases are reduced by 40%.

The optimal cropping pattern under Scenario I suggest 98% of the CCA to be irrigated during the season with lower net return per hectare. Under Scenario – II, the entire CCA of the distributary can be used for cultivation with the designed cropping pattern assuring higher net return. Restricting 1/3rd of the CCA for cultivation of heavy duty crops in Scenario – III, increase the net benefit. However, this scenario is not feasible if the canal

Table 5. *Effect of water availability on optimal cropping pattern*

Scenario	Water Availability (%)	Area under different crops (ha)			Net Return (Rs ha^{-1})	Decrease in NR (%)
		Heavy	Medium	Low		
II	100	8860.89	2180.29	231.33	24332	-
	90	7645.65	2581.03	1045.82	23593	3.04
	75	5656.98	3467.80	2147.73	22516	7.46
	60	2974.86	4820.02	3477.63	21154	13.06
III	100	8798.28	2399.42	74.81	24408	-
	90	7493.15	3114.79	664.57	23779	2.58
	75	Not feasible				
	60	Not feasible				
IV	100	8768.35	2504.16	0.00	24445	-
	90	7227.32	4045.19	0.00	24103	1.40
	75	4820.33	6396.07	56.11	23537	3.71
	60	2017.88	8169.44	1085.19	22322	8.68

releases are reduced due to any reason. The optimal cropping pattern for maximization of net benefit under Scenario – IV suggests allocation of 77% and 23% of the CCA under heavy and medium duty crops with no allocation for light duty crops. This again may not be advisable for the command area from the self-sufficiency point of view.

Hence, it can be concluded that the cropping pattern obtained under Scenario - II may be adopted for the command area of the distributary for optimal land and water utilization, and generation of requisite employment. However, optimization of the cropping pattern should be carried out when the canal releases are changed to some reason.

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