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ORIGINAL ARTICLE

Optimal cropping pattern design for a major distributary of Hirakud canal command in India

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Abstract

Gravity flow on field to field flooding basis is prevalent in most of the canal command areas in India. Furthermore, the canals being mostly unlined and at many sections ill maintained, enormous conveyance loss of water occurs causing dwindling crop production. Hirakud canal command area located in India is no exception to this predicament. Thus, augmentation of irrigation infrastructures vis-à-vis prudent crop planning is of paramount importance for increasing the overall efficiency of the canal system. This paper describes development of optimal crop planning in the Hirakud command area by considering different objectives of planning (scenarios) so that improvement in irrigation efficiency, in terms of water productivity could be feasible. Among various scenarios, the cropping pattern obtained under Scenario—II, i.e. to utilize the maximum area for cultivation, under the constraint of limiting water availability for each outlet was found to be feasible for optimal land and water utilization and generation of requisite employment. However, keeping in view the affinity of the farmers towards paddy (a heavy duty crop), Scenario—III i.e. to utilize the maximum area for cultivation with the constraints of limited irrigation water availability, and providing irrigation to heavy duty crops for at least one-third of the culturable command area of each outlet, can be adopted.

Keywords Hirakud command area · Optimal crop planning · Surplus–deficit analysis · Optimization · Linear programming

Introduction

Irrigation has been a high priority sector for economic development of India with huge investment on water resources development and irrigation infrastructure. After independence of India, a boost in agricultural production happened due to creation of irrigation facilities through development of major and medium irrigation projects. However, the overall irrigation efficiency in canal irrigation system in India is only 30–65% depending on project location and management (Central Water Commission 2014). The efficiencies of the major and medium irrigation projects in India are around 40%, while in the minor and groundwater sectors, it is above 60% (Verma and Phansalkar 2007). According to the Food and Agriculture Organization (FAO), the overall water use efficiency for irrigated agriculture in developing countries averages to about 38% (Tropp 2006). While studying the irrigation application efficiency in Bargarh distributary (distributary is a part of canal water distribution system) of Hirakud canal command (India), it was observed within the range of 24–53% (DWM 2014). Low overall efficiency of irrigation projects leads to poor utilization of irrigation potential created at huge cost. To overcome the difficulties of 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. Furthermore, the scope for modification of the structures according to the change in water available for irrigation i.e., due to 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 irrigation water managers need to be equipped with scientific tools of

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proven credibility. Optimization of cropping pattern with the constraints of land and water availability is one such tool.

The development of optimization models for land and water management has expanded rapidly in last decade, and now-a-days commonly used by irrigation policy makers (Tan et al. 2017; Difallah et al. 2017). An optimization model requires an objective function and one or more constraints, expressed in mathematical form. In agriculture, the objective functions such as maximization of net return, land use etc., and the constraints such as land, water and other resources availability can be expressed in 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. Vedula and Nagesh Kumar (1996) developed a mathematical programming model to determine the optimal operating policy and crop water allocation to different crops for a single purpose irrigation reservoir by combining linear programming and dynamic programming models. Paul et al. (2000) developed optimal resources allocation strategies for a canal command in the semi-arid region of India, considering the competition of crops in a season, both for irrigation water and area of cultivation. Singh et al. (2001) used linear programming model to the Shahi Distributary to determine the optimal cropping pattern for a command area of 11,818 ha. It was found that the water available in the command area may support optimally 4981, 3560, 1817, 632, 355, 87 and 3653 ha of wheat, sugarcane, mustard, lentil, potato, chick pea and rice, respectively, to get a maximum net return of Rs. 185 million. Sethi et al. (2002) developed a linear programming optimisation model for optimal crop planning and groundwater management and thereby maximising net returns in a coastal basin in the state of Odisha. The feasibility of conjunctive use management was analyzed using a mathematical model in the Sharda Sahayak command area of Sultanpur district of Uttar Pradesh, India (Mani and Singh 2009). The simple economic—engineering optimization models are feasible and can be easily implemented to explore the possibilities of conjunctive use of surface and groundwater using linear programming and to arrive at an optimal cropping pattern for optimal utilization of water for maximising net benefits.

Safavi et al. (2010) developed a simulation–optimization model for the conjunctive use of surface water and groundwater on a basin-wide scale in the Najafabad plain of west central Iran. They developed an ANN model as a simulator of surface water and groundwater interaction and linked it with a GA-based optimization model. The results of the model demonstrated the importance of conjunctive use approach for planning and management of water resources in semi-arid regions. Use of the “TORA-version 1.03” optimization model to arrive at optimal allocation plan of surface water and ground water in Sultanpur district’s water availability in the eastern Uttar Pradesh of India indicated that conjunctive use options are feasible which would enhance the overall benefits from cropping activities (Maurya 2013). Mohanty et al. (2013) developed a simulation–optimisation model for a well command of eastern India and suggested optimal cropping pattern for the study area. The results of simulation–optimization modelling indicated that if the suggested optimal cropping patterns are adopted in the study area, the net annual irrigation water requirements will be reduced by 28, 35 and 40%, and net annual income will be increased by 28, 23 and 17% during wet, normal and dry scenarios, respectively. Chen et al. (2014) developed an optimisation model for large scale conjunctive use of surface water and groundwater resources in Chou-Sui alluvial basin in Taiwan. An ANN model was trained to replace the physically based model and linear programming was used to create the optimisation model. The model showed that conjunctive use of water resources is possible while maintaining a stable and sustainable groundwater levels.

Hirakud canal irrigation system in the state of Odisha is affected by low water productivity, with paddy being the major crop in both *Kharif* (*monsoon*) and *Rabi* (*post-monsoon*) seasons. Although the productivity of paddy in the region is not very encouraging at 2.05 t ha^{-1} [Govt. of Odisha (India) 2013], the farmers are inclined towards the crop. This may be due to the readily available market for paddy, and the farmers, mostly small and marginal, are not willing to take the risk for marketing of the other crop produces. While studying the sustainability of paddy-dominated cropping system in the Hirakud Canal Command, Raul et al. (2008) estimated that the mean annual deficit of irrigation water amounts to around 1956 million m^3 which is mainly due to extensive paddy cultivation in the monsoon and non-monsoon seasons and to a lesser extent due to the sugarcane crop. This deficit in water availability can be mitigated by replacing the existing non-monsoon paddy by other crops such as oilseeds and pulses which require less water compared to paddy. Optimal allocation of paddy and other low water requiring crops in the command area also has the potential to increase the net return from the system. However, allocation of areas for crops of different quantums of water demand should be done judiciously so as to ensure utilization of maximum land for cultivation and water available for irrigation. Keeping these in view, the present study was conducted with various scenario analyses for optimal water allocation and crop planning in the Hirakud command area using linear programming model.

Materials and methods

Study area

The Hirakud canal command area lies between 20°43′–21°41′N latitude and 82°39′–83°58′E longitude (Fig. 1) and falls under the Western Central Table Land Agro-climatic zone of Odisha (India). Canal irrigation is provided to the command through three canal distribution systems, namely; Bargarh main canal, Sason main canal and Sambalpur distributary. Bargarh main canal off takes

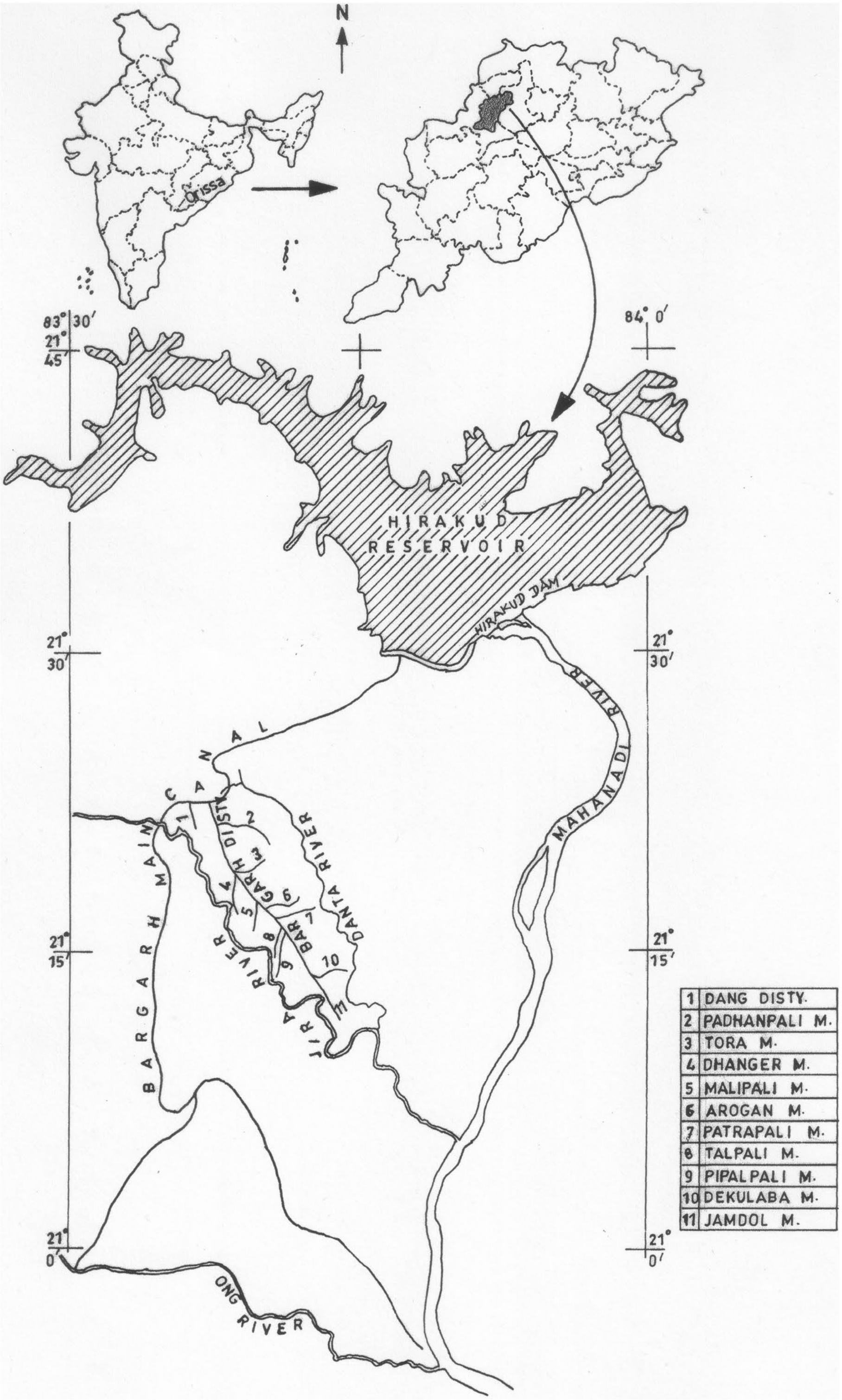


Fig. 1 Location map of the study area

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 Bargarh distributary, which off takes from the left of Bargarh main canal at 26.335 km RD. The distributary has 15 minors and sub-minors along with some direct outlets from it at different reaches. 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 10–45 °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 (Central Ground Water Board 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 in rest of the months. Paddy is the predominant crop cultivated both in monsoon and non-monsoon seasons.

Deficit–surplus analysis

The study focussed on assessment of the irrigation 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 the supply; and devising intervention so as to minimize the demand–supply gap. The details of direct outlets, minors and sub-minors operating from the system are presented in Table 1. The Department of Water Resources, Govt. of Odisha (India) has proposed cropping pattern as per the water supply at different outlets for the season *Rabi* (post-monsoon cropping season) 2013. The release of water from the canal which is continuous (without any control or closure during the cropping season) and the adopted cropping pattern of the command area of individual minor/sub-minor (including the direct outlets) during the *Rabi* 2013 season were taken into account for the analysis.

The canal release is continuous for the cropping period (approximately 100 days) except the closure, for minor maintenance for 3 days. The water availability at each outlet (minor/sub-minors and direct outlets) were calculated from their discharge rate and the duration operation as follows:

$$\mathrm{WA}_i = 36 \times 24 \times q_i \times N, \tag{1}$$

where WA_i is the total water available at outlet '*i*' (ha-cm), q_i is the discharge of outlet '*i*' (cumec), assumed to be constant throughout the operating period of the outlet and N is the number of days of operation of the outlet.

Since the water release through the outlets are not controlled, the crops grown in the command area were divided into three groups viz. heavy, medium and low, according to their water requirement for entire life cycle. The water requirement of the heavy duty crops (paddy, sugarcane etc.), medium duty crops (groundnut, wheat, vegetables etc.) and the low duty crops (blackgram, greengram, pea, mustard etc.) are presented in the Table 2.

Table 1 Details of outlets from the Bargarh Distributary System

Sl. no.	Name of Direct Outlets/Minors/Sub-Minors	Discharge (cumec)	CCA (ha)	Reach
1	Bargarh Dist DO (Head)	1.358	1639.00	Head
2	Padhanpali Minor	0.917	1208.62	
3	Jamurda Sub Minor	0.275	347.43	
4	Barahgoda Sub Minor	0.244	262.07	
5	Amsada Sub Minor	0.237	321.09	
6	Tora Minor	0.266	339.81	
7	Dhanger Minor	0.380	532.61	
8	BargarhDist DO (Middle)	0.669	806.79	Middle
9	Malipali Minor	0.700	921.61	
10	Khandahata Sub Minor	0.390	553.92	
11	Argaon Minor	0.458	653.19	
12	Patrapali Minor	0.283	434.28	
13	BargarhDist DO (Tail)	1.770	2135.99	Tail
14	Talpali Minor	0.228	388.40	
15	Piplipali Minor	0.322	453.48	
16	Dekulba Minor	0.328	260.95	
17	Dekulba Sub Minor	0.346	555.29	
18	Jamdol Minor	0.222	351.47	
Total for the distributary		9.393	12166,00	

Table 2 Details of crop parameters used in the analysis

Crop type	Crops	Water requirement[a] (cm)
Heavy	Paddy, sugarcane etc	100
Medium	G. nut, wheat, vegetables etc	50
Low	Black gram, green gram, pea, mustard etc	30

[a] The total water requirement for the entire cropping period

The total crop water requirements for the command area of each outlet (direct outlet/minor/sub-minor) is calculated using the following expression:

$$\mathrm{WR}_i = A_H^i \times D_H + A_M^i \times D_M + A_L^i \times D_L, \tag{2}$$

where WR_i is the total water requirement for the command area of outlet '*i*' (ha-cm), A_H^i, A_M^i and A_L^i 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 at each outlet is compared with its crop water requirement in the same command area and deficit surplus analysis is carried out. If $\mathrm{WR}_i > \mathrm{WA}_i$, then the outlet is operating under deficit condition, if $\mathrm{WR}_i < \mathrm{WA}_i$, then the outlet is operating under surplus condition and if $\mathrm{WR}_i = \mathrm{WA}_i$, 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 function:

$$\mathrm{Min}\,:\,Z_i = \mathrm{WA}_i - \mathrm{WR}_i. \tag{3}$$

Constraints:

$$\begin{aligned} &A_H^i + A_M^i + A_L^i \le \mathrm{CCA}^i \\ &A_H^i, A_M^i, A_L^i \ge 0, \end{aligned} \tag{4}$$

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 function:

$$\mathrm{Max}\,:\,Z_i = A_H^i + A_M^i + A_L^i. \tag{5}$$

Constraints:

$$A_H^i \times D_H + A_M^i \times D_M + A_L^i \times D_L \le \mathrm{WA}_i. \tag{6}$$

$$\begin{aligned} &A_H^i + A_M^i + A_L^i \le \mathrm{CCA}^i \\ &A_H^i,\ A_M^i,\ A_L^i \ge 0, \end{aligned} \tag{7}$$

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); and the other terms are same as defined above. However, it is assumed that the total cropped area Z_i may not exceed the culturable area available under the outlet 'i' i.e., CCA^i.

Scenario—III

Under this scenario, the main objective is to utilize the maximum area for cultivation 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:

Objective function:

$$\mathrm{Max}\,:\,Z_i = A_H^i + A_M^i + A_L^i. \tag{8}$$

Constraints:

$$A_H^i \times D_H + A_M^i \times D_M + A_L^i \times D_L \le \mathrm{WA}_i, \tag{9}$$

$$A_H^i \ge \mathrm{CCA}^i / 3, \tag{10}$$

$$\begin{aligned} &A_H^i + A_M^i + A_L^i \le \mathrm{CCA}^i \\ &A_H^i, A_M^i, A_L^i \ge 0, \end{aligned} \tag{11}$$

where the terms are same as defined above. Similar to the Scenario II, it is assumed that the total cropped area Z_i may not exceed the culturable area available under the outlet 'i' i.e., CCA^i.

Scenario—IV

Under this scenario, the main objective is to maximize the net agricultural return from the command area of each outlet. The constraints 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:

Objective function:

$$\mathrm{Max}\,:\,Z_i = \mathrm{NR}_H \times A_H^i + \mathrm{NR}_M \times A_M^i + \mathrm{NR}_L \times A_L^i. \tag{12}$$

Constraints:

$$A_H^i \times D_H + A_M^i \times D_M + A_L^i \times D_L \le \mathrm{WA}_i, \tag{13}$$

$$\begin{aligned} &A_H^i + A_M^i + A_L^i \le \mathrm{CCA}^i \\ &A_H^i, A_M^i, A_L^i \ge 0, \end{aligned} \tag{14}$$

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. All the scenarios were analyzed using Excel Solver.

Results and discussion

Deficit–surplus analysis

The cropping pattern, as proposed by the Department of Water Resources, Govt. of Odisha (India) for *Rabi* 2013, water available and water demand under the command of each minor/sub-minor of the Bargarh distributary system is presented in Table 3. Deficit status was observed for all the minors/sub-minors of the distributary system at the head reach. Water is surplus at most of the minors located in the middle reach; whereas mixed status was observed for the outlets in the tail reach. This is contrary to the normal operation of a surface water irrigation system, in which the head reach is water surplus and the middle and the tail reach are water deficit. The present situation is due to the fact that there are more unauthorized (not designed originally) outlets in the head end of the canal. Hence, the actual amount of water used in the head end of the canal is more than the designed theoretical water supply. Thus, in the head end outlets, 95% area of total CCA is put under crops, whereas in middle and lower outlets only 75% area of the total CCA is put under crops (Table 3). In the deficit–surplus analysis, comparison has been made between water requirements of actual cropped area with theoretical design water supply. Hence, water deficit in the head end outlets is observed. It is also observed that water deficit prevails in the distributary system as a whole, which is likely due to the water deficit at all the outlets in the head reach.

Optimal cropping pattern scenario

Scenario–I

The optimal allocation of areas for different types of crops under this scenario for each outlet and the total system is presented in Table 4. It was observed that to maintain the optimality of water use (with no surplus or deficit), only about 82.4% of the total command area should be irrigated. However, there would be surplus water in the command area of Dekulba Minor even if the entire CCA is cultivated with heavy duty crops. This also indicates that more water could be diverted to the Dekulba Sub-Minor or discharge in the Dekulba Minor could be reduced and the surplus water could be provided to the Jamdol Minor (at the tail end) to increase the cultivated area under the latter. Under this scenario only 10026,75 ha of the total command area of 12,166 ha can be provided irrigation for the *Rabi* season with average rate

Table 3 Deficit–surplus analysis of the Bargarh Distributary System

Sl. No.	Name of Minor	CCA (ha)	Cropping pattern (ha) *Rabi* 2013				Water Req. (ha-cm)	Water Av. (ha-cm)	Status
			Heavy	Medium	Low	Total			
1	BargarhDist DO (Head)	1639.00	1225.02	230.14	92.77	1547.93	136,792	117,331	Deficit
2	Padhanpali Minor	1208.62	784.00	299.00	58.00	1141.00	95,090	79,229	Deficit
3	Jamurda Sub Minor	347.43	257.40	10.00	40.00	307.40	27,440	23,760	Deficit
4	Barahgoda Sub Minor	262.07	166.50	95.00	0.00	261.50	21,400	21,082	Deficit
5	Amsada Sub Minor	321.09	270.90	35.00	14.00	319.90	29,260	20,477	Deficit
6	Tora Minor	339.81	307.90	21.00	0.00	328.90	31,840	22,982	Deficit
7	Dhanger Minor	532.61	426.10	87.00	16.00	529.10	47,440	32,832	Deficit
	Head	4650.63	3437.82	777.14	220.77	4435.73	389,262	317,693	Deficit
8	BargarhDist DO (Middle)	806.79	403.42	121.03	80.67	605.12	48,814	57,802	Surplus
9	Malipali Minor	921.61	460.83	138.22	92.16	691.21	55,759	60,480	Surplus
10	Khandahata Sub Minor	553.92	276.96	83.08	55.39	415.43	33,512	33,696	Surplus
11	Argaon Minor	653.19	326.59	97.98	65.31	489.88	39,517	39,571	Surplus
12	Patrapali Minor	434.28	217.15	65.12	43.43	325.70	26,274	24,451	Deficit
	Middle	3369.79	1684.95	505.43	336.96	2527.34	203,875	216,000	Surplus
13	BargarhDist DO (Tail)	2135.99	1068.00	320.42	213.59	1602.01	129,229	152,928	Surplus
14	Talpali Minor	388.40	194.20	58.27	38.83	291.30	23,498	19,699	Deficit
15	Piplipali Minor	453.48	226.75	68.02	45.33	340.10	27,436	27,821	Surplus
16	Dekulba Minor	260.95	130.47	39.14	26.09	195.70	15,787	28,339	Surplus
17	Dekulba Sub Minor	555.29	277.65	83.30	55.52	416.47	33,596	29,894	Deficit
18	Jamdol Minor	351.47	175.74	52.71	35.15	263.60	21,264	19,181	Deficit
	Tail	4145.58	2072.81	621.86	414.51	3109.18	250,809	277,862	Surplus
	Total	12166,00	7195.58	1904.43	972.24	10072,25	843,947	811,555	Deficit

Table 4 Optimal allocation of land for different crop types under Scenario–I

Sl. no.	Name of Minor	CCA (ha)	Cropping pattern (ha)				WA (ha-cm)	WR (ha-cm)	Surplus/deficit	Net return (Rs)	NR/ha (Rs/ha)
			Heavy	Medium	Low	Total					
1	BargarhDist DO (Head)	1639.00	1027.72	162.47	214.51	1404.71	117,331	117,331	0	25,565,683	18,200
2	Padhanpali Minor	1208.62	665.63	239.82	22.49	927.94	79,229	79,229	0	17,179,781	18,514
3	Jamurda Sub Minor	347.43	225.96	4.95	30.57	261.47	23,760	23,760	0	4,960,129	18,970
4	Barahgoda Sub Minor	262.07	163.95	93.73	0.00	257.68	21,082	21,082	0	4,684,952	18,181
5	Amsada Sub Minor	321.09	200.35	5.17	6.10	211.63	20,477	20,477	0	4,157,862	19,647
6	Tora Minor	339.81	161.29	120.64	27.39	309.32	22,982	22,982	0	5,364,012	17,342
7	Dhanger Minor	532.61	236.06	118.03	110.82	464.91	32,832	32,832	0	7,821,457	16,824
8	BargarhDist DO (Middle)	806.79	470.49	154.57	100.79	725.85	57,802	57,802	0	12,937,911	17,824
9	Malipali Minor	921.61	496.06	155.84	102.73	754.63	60,480	60,480	0	13,491,561	17,878
10	Khandahata Sub Minor	553.92	278.34	83.77	55.80	417.91	33,696	33,696	0	7,492,854	17,930
11	Argaon Minor	653.19	326.99	98.18	65.43	490.60	39,571	39,571	0	8,797,730	17,932
12	Patrapali Minor	434.28	203.55	58.32	39.35	301.22	24,451	24,451	0	5,417,930	17,987
13	BargarhDist DO (Tail)	2135.99	1244.86	408.85	266.65	1920.36	152,928	152,928	0	34,229,740	17,825
14	Talpali Minor	388.40	165.85	44.09	30.32	240.27	19,699	19,699	0	4,342,255	18,073
15	Piplipali Minor	453.48	229.62	69.46	46.19	345.27	27,821	27,821	0	6,188,591	17,924
16	Dekulba Minor	260.95	260.95	0.00	0.00	260.95	28,339	26,095	2244	5,218,964	20,000
17	Dekulba Sub Minor	555.29	198.91	129.46	117.67	446.04	29,894	29,894	0	7,332,208	16,438
18	Jamdol Minor	351.47	120.01	110.00	56.00	286.01	19,181	19,181	0	4,722,186	16,511
	Total	12166,00	6676.59	2057.34	1292.82	10026,75	811,555	809,311	2244	179,905,807	17,943

of net return of Rs17,943/-per ha of the irrigated area (1 USD ≈ Indian Rupees, Rs. 67).

Scenario—II

The optimal allocation of areas under different types of crops under this scenario for each outlet and the total system is presented in Table 5. The results revealed that 100% of the culturable command area of the distributary can be irrigated, if the designed cropping pattern could be followed. However, similar to the first scenario, the use of irrigation water is not optimal for the Dekulba Minor. Though the total command area can be provided irrigation under this scenario, there would be reduced average rate of net return (Rs. 16,426/-) per ha of the irrigated area compared to the previous scenario.

Scenario—III

The optimal allocation of areas under different types of crops under this scenario for each outlet and the total system is presented in Table 6. It is observed from the table that this scenario would give more net return than that of the first scenario, with provision of irrigation for 99.7% of the CCA. However, because of the constraint of 1/3rd area under heavy duty crops, the average rate of net return (Rs. 16,365/-) per ha of the irrigated area under this scenario is less than that of the second scenario.

Scenario—IV

The optimal allocation of areas under different types of crops under this scenario for each outlet and the total system is presented in Table 7. The cropping pattern under this scenario would give the maximum net agricultural return from the command area of the distributary with 100% land utilization and without any water deficit in any of the outlets. However, since no area is allocated for low duty crops, which includes pulses and oilseeds, this scenario may not be practicable.

From the analysis of the scenarios, it is observed that the constraints of land and water availability are satisfied under all the scenarios except for the Dekulba Minor, which is water surplus. Hence, all the outlets of the distributary can be operated optimally with the adoption of the designed cropping pattern in the command areas of the individual outlets except for the Dekulba Minor. The net return and the net return per unit area under different scenarios are presented in Fig. 2. The net return is highest under scenario IV, whereas net return/ha is highest under scenario I. The water productivity, calculated as net benefit per unit of water availability, for the Scenarios I–IV are computed to be Rs. 222, 246, 245 and 250 per ha-cm of water, respectively.

The optimal cropping pattern, under Scenario I, providing maximum net return per unit area of cultivation suggests less than 5/6th of the CCA to be irrigated during the season, which may not be practicable in the field. Under Scenario—II, the entire CCA of the distributary can be used for cultivation with the designed cropping pattern assuring higher net return. Though the net return per unit area under this scenario is about 8.5% less than that of Scenario—I, its water productivity is higher and would generate more employment for the agricultural labourers. Restricting 1/3rd of the CCA for cultivation of heavy duty crops in Scenario—III resulted in decrease of the net benefit, net benefit per unit area, water productivity and land utilization marginally compared to those of Scenario—II (Fig. 2). The optimal cropping pattern for maximization of net benefit under Scenario—IV suggests allocation of 1/3rd and 2/3rd 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.

Conclusion

The deficit–surplus analysis of the Bargarh Distributary in Hirakud canal command suggests sub-optimal operation of the outlets. There are gaps in the irrigation water supply and crop water requirement with the prevailing cropping pattern. To optimize the cropping pattern, without changing the canal release, out of the four scenarios considered, Scenario—II and Scenario—III were found to be adoptable. 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, if the affinity of the farmers towards paddy (a heavy duty crop) cannot be avoided then the designed cropping pattern under Scenario—III may be adopted. The findings of the optimisation model can be implemented in the field through training and demonstration of Government extension agencies and involvement of local water users associations.

Table 5 Optimal allocation of land for different crop types under Scenario—II

Sl. no.	Name of Minor	CCA (ha)	Cropping pattern (ha)				WA (ha-cm)	WR (ha-cm)	Surplus/deficit	Net Return (Rs)	NR/ha (Rs/ha)
			Heavy	Medium	Low	Total					
1	BargarhDist DO (Head)	1639.00	897.00	268.57	473.44	1639.00	117,331	117,331	0	27,649,713	16,870
2	Padhanpali Minor	1208.62	387.67	791.66	29.28	1208.62	79,229	79,229	0	19,979,746	16,531
3	Jamurda Sub Minor	347.43	188.47	7.21	151.74	347.43	23,760	23,760	0	5,698,516	16,402
4	Barahgoda Sub Minor	262.07	188.85	0.00	73.22	262.07	21,082	21,082	0	4,655,640	17,765
5	Amsada Sub Minor	321.09	117.95	129.38	73.77	321.09	20,477	20,477	0	5,184,851	16,147
6	Tora Minor	339.81	152.18	106.76	80.86	339.81	22,982	22,982	0	5,615,485	16,525
7	Dhanger Minor	532.61	175.08	229.90	127.63	532.61	32,832	32,832	0	8,481,699	15,925
8	BargarhDist DO (Middle)	806.79	412.49	236.19	158.12	806.79	57,802	57,802	0	13,689,971	16,968
9	Malipali Minor	921.61	383.47	299.45	238.69	921.61	60,480	60,480	0	15,025,416	16,303
10	Khandahata Sub Minor	553.92	188.50	194.17	171.25	553.92	33,696	33,696	0	8,737,562	15,774
11	Argaon Minor	653.19	219.70	229.84	203.65	653.19	39,571	39,571	0	10,285,330	15,746
12	Patrapali Minor	434.28	116.69	162.74	154.85	434.28	24,451	24,451	0	6,633,064	15,274
13	BargarhDist DO (Tail)	2135.99	1090.44	625.85	419.69	2135.99	152,928	152,928	0	36,233,037	16,963
14	Talpali Minor	388.40	70.06	157.14	161.19	388.40	19,699	19,699	0	5,692,692	14,657
15	Piplipali Minor	453.48	158.03	157.71	137.74	453.48	27,821	27,821	0	7,179,140	15,831
16	Dekulba Minor	260.95	260.95	0.00	0.00	260.95	28,339	26,095	2244	5,218,964	20,000
17	Dekulba Sub Minor	555.29	127.53	215.41	212.34	555.29	29,894	29,894	0	8,330,003	15,001
18	Jamdol Minor	351.47	84.82	134.96	131.69	351.47	19,181	19,181	0	5,301,087	15,083
	Total	12166,00	5219.89	3946.94	2999.17	12166,00	811,555	809,311	2244	199,591,915	16,406

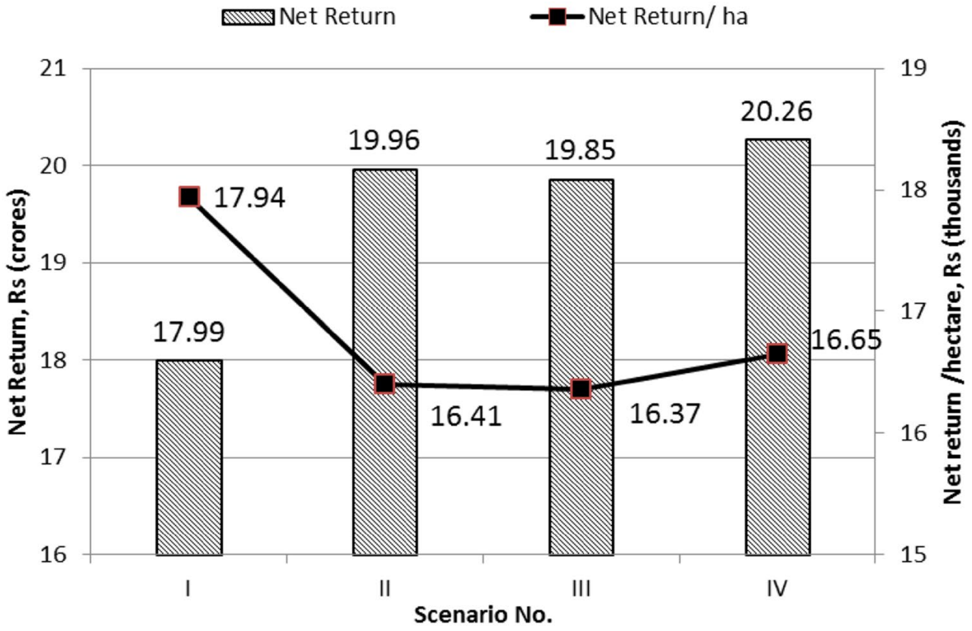
Table 6 Optimal allocation of land for different crop types under Scenario—III

Sl. no.	Name of Minor	CCA (ha)	Cropping pattern (ha)				WA (ha-cm)	WR (ha-cm)	Surplus/deficit	Net return (Rs)	NR/ha (Rs/ha)
			Heavy	Medium	Low	Total					
1	BargarhDist DO (Head)	1639.00	854.30	417.99	366.71	1639.00	117,331	117,331	0	27,756,441	16,935
2	Padhanpali Minor	1208.62	511.72	357.50	339.40	1208.62	79,229	79,229	0	19,669,632	16,275
3	Jamurda Sub Minor	347.43	163.08	96.09	88.26	347.43	23,760	23,760	0	5,762,002	16,585
4	Barahgoda Sub Minor	262.07	174.24	51.12	36.70	262.07	21,082	21,082	0	4,692,159	17,904
5	Amsada Sub Minor	321.09	126.68	98.82	95.59	321.09	20,477	20,477	0	5,163,029	16,079
6	Tora Minor	339.81	155.34	95.72	88.75	339.81	22,982	22,982	0	5,607,597	16,502
7	Dhanger Minor	532.61	191.74	171.60	169.27	532.61	32,832	32,832	0	8,440,056	15,847
8	BargarhDist DO (Middle)	806.79	421.27	205.43	180.09	806.79	57,802	57,802	0	13,668,002	16,941
9	Malipali Minor	921.61	391.26	272.16	258.19	921.61	60,480	60,480	0	15,005,920	16,282
10	Khandahata Sub Minor	553.92	192.12	181.51	180.30	553.92	33,696	33,696	0	8,728,513	15,758
11	Argaon Minor	653.19	223.90	215.13	214.15	653.19	39,571	39,571	0	10,274,833	15,730
12	Patrapali Minor	434.28	154.39	30.76	249.13	434.28	24,451	24,451	0	6,538,791	15,057
13	BargarhDist DO (Tail)	2135.99	1113.66	544.62	477.72	2135.99	152,928	152,928	0	36,175,001	16,936
14	Talpali Minor	388.40	129.47	0.00	225.09	354.55	19,699	19,699	0	5,290,374	14,921
15	Piplipali Minor	453.48	161.09	147.00	145.39	453.48	27,821	27,821	0	7,171,494	15,814
16	Dekulba Minor	260.95	260.95	0.00	0.00	260.95	28,339	26,095	2244	5,218,964	20,000
17	Dekulba Sub Minor	555.29	189.08	0.00	366.21	555.29	29,894	29,894	0	8,176,136	14,724
18	Jamdol Minor	351.47	123.38	0.00	228.09	351.47	19,181	19,181	0	5,204,687	14,808
	Total	12166,00	5537.67	2885.45	3709.04	12132,16	811,555	809,311	2244	198,543,630	16,365

Table 7 Optimal allocation of land for different crop types under Scenario—IV

Sl. no.	Name of Minor	CCA (ha)	Cropping pattern (ha)				WA (ha-cm)	WR (ha-cm)	Surplus/deficit	Net return (Rs)	NR/ha (Rs/ha)
			Heavy	Medium	Low	Total					
1	BargarhDist DO (Head)	1639.00	707.62	931.38	0.00	1639.00	117,331	117,331	0	28,123,150	17,159
2	Padhanpali Minor	1208.62	375.96	832.65	0.00	1208.62	79,229	79,229	0	20,009,030	16,555
3	Jamurda Sub Minor	347.43	127.77	219.65	0.00	347.43	23,760	23,760	0	5,850,260	16,839
4	Barahgoda Sub Minor	262.07	159.56	102.51	0.00	262.07	21,082	21,082	0	4,728,860	18,044
5	Amsada Sub Minor	321.09	88.44	232.65	0.00	321.09	20,477	20,477	0	5,258,620	16,377
6	Tora Minor	339.81	119.84	219.97	0.00	339.81	22,982	22,982	0	5,696,350	16,763
7	Dhanger Minor	532.61	124.03	408.59	0.00	532.61	32,832	32,832	0	8,609,330	16,164
8	BargarhDist DO (Middle)	806.79	349.24	457.55	0.00	806.79	57,802	57,802	0	13,848,090	17,164
9	Malipali Minor	921.61	287.99	633.62	0.00	921.61	60,480	60,480	0	15,264,110	16,562
10	Khandahata Sub Minor	553.92	120.00	433.92	0.00	553.92	33,696	33,696	0	8,908,810	16,083
11	Argaon Minor	653.19	138.24	514.95	0.00	653.19	39,571	39,571	0	10,488,980	16,058
12	Patrapali Minor	434.28	54.74	379.53	0.00	434.28	24,451	24,451	0	6,787,912	15,630
13	BargarhDist DO (Tail)	2135.99	922.57	1213.43	0.00	2135.99	152,928	152,928	0	36,652,731	17,160
14	Talpali Minor	388.40	5.59	382.81	0.00	388.40	19,699	19,699	0	5,853,884	15,072
15	Piplipali Minor	453.48	102.94	350.54	0.00	453.48	27,821	27,821	0	7,316,881	16,135
16	Dekulba Minor	260.95	260.95	0.00	0.00	260.95	28,339	26,095	2244	5,218,964	20,000
17	Dekulba Sub Minor	555.29	42.60	512.69	0.00	555.29	29,894	29,894	0	8,542,345	15,384
18	Jamdol Minor	351.47	32.15	319.32	0.00	351.47	19,181	19,181	0	5,432,775	15,457
	Total	12166,00	4020.22	8145.78	0.00	12166,00	811,555	809,311	2244	202,591,082	16,652

Fig. 2 Net return and net return per hectare in Bargarh distributary under different scenarios



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