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Econometric analysis of optimization of water among different sectors

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ABSTRACT

Water being a limited resource, its efficient use is very vital and basic to the very survival of the ever-increasing population. Every effort must be made for the best use of available water so as to make possible a high level of continuous production per unit volume of water per unit area of cropped land and per unit time. Water is a precious commodity that will become even more valuable as time goes by. Hence great emphasis is to be given for efficient use of this scarce resource but valuable resource especially in the command areas of the irrigation projects in order to reap the benefits offered by the technological innovations in farming. The increase in demand will be higher for urban and industrial uses than for agriculture. The total demand for water in India is projected to be 886 billion cubic metre in 2030. However supply expansion will not be sufficient to meet increasing demands. Comprehensive reforms are required to improve the incentives at each level of the water allocation process in order to improve the efficiency of agricultural water use and sustain crop yields and output growth to meet the rising food demand while allowing transfers of water out of agriculture. The proposed study was taken up in Bhavani basin where water transfer has been an increasing phenomenon over years. The study examined optimum water allocation among different sectors and ensuring equity in distribution of water to all the beneficiaries of the ayacut.

Keywords: Water optimization; ayacut; plan; sectors

INTRODUCTION

In India, average food grain consumption at present is 550 g per capita per day whereas the corresponding figures in China and USA are 980 and 2850 g respectively (Anon 2019b). Present annual requirement on the basis of present consumption level (550 g) for the country is about 200 million tonnes (Anon 2019c). A moderate rise in consumption level of 750 g per capita per day is considered to be realistic for assessment of future needs. The annual food grain requirement of the country thus works out to be 450 MT by the year 2050 (Shah 2016). The real challenge is providing additional irrigation water to increase food production while satisfying the rising demand for water from other competing sectors (Srinivasan and Kulkarni 2014). Since irrigation sector being the largest consumer of water, greater attention in water management is needed in this sector. That is almost all the utilizable potential will have to be harnessed to meet the demand for agriculture, industry, energy generation and domestic consumption. Even among the user sectors, the consumption of water in India is highly skewed (Thakkar 2018).

One of the important objectives of this study was to optimize water use among agricultural, domestic, livestock and industrial sectors. This is important since due to increasing competition among different sectors for water as well as high willingness to pay (WTP) order industries, it is expected that industrial sector may demand more water as reported by Agrawal (2012).

The Tamil Nadu state water policy 2002 gives first priority for domestic water needs (Pavelic et al 2015). Hence agriculture may face more competition. However by optimal allocation of the available supplies, it is also possible to maximize the return from water (Palanisami 2013).

A portion of the growing demand for water will be met though new investment in irrigation and

water supply systems and some potential exists for expansion of non-traditional sources of water supply (Anon 2019a). However supply expansion will not be sufficient to meet increasing demands.

The rapidly growing urban and industrial water demands will need to be met increasingly from water transfers out of irrigated agriculture (Anon 2018). Hence it was one of the important objectives in this study and 150 samples were analyzed and assessed the extent and nature of water transfer in the lower Bhavani basin.

The public works department (PWD) controlled water allocation up to the distributory level while farmers were responsible for farm-level water distribution (Anon 2011, 2013). In the wet season, water was distributed (both old and new ayacut) via continuous flooding of the fields; in the dry season, farmers rotate their turns (in LBP) during alternate weeks only. This policy indicates how the allocation of water in Tamil Nadu has evolved to become user based which is a prerequisite for market-based water allocation (Rathore 2011).

In an eight-day period of water supply (in LBP) to a distributory from the canal, water allowance (WA) to a farmer was calculated where WA is the time (minutes or hours) multiplied by the area owned. This determined the total time of water use allowed for each farmer. Farmers who had wells and farmers whose water requirements were not needed from their turn exchanged their turns with their neighbours (eg Thindal distributory of the LBP) using the concept of water allowance defined in terms of number of hours per unit area (Anon 2016). Currently two major forms of water transfer have been observed in the lower Bhavani basin ie within the basin (agriculture and non-farm sector) and between the basins (agriculture and non-farm sector).

METHODOLOGY

Primary data were collected from 150 samples and were analyzed.The optimum water allocation between different sectors viz agriculture, domestic and industries in the lower Bhavani basin was assessed. In the present study profit maximization has been assumed as the objective at the ayacut level and attempts were made to develop optimum plan for old ayacuts.

Algebraic formulation of the linear programming model

The algebraic formulation of the optimization model is given Table 1 and the activities, parameters and constraints are described.

The objective function was to maximize the aggregate gross income from the crop activities plus domestic sector plus industrial sector subject to technical constraints and level of resource availability.

$$\text{Maximize } Z = \sum_{s=1}^{3} \sum_{c=1}^{13} gr_{asc} X_{sc} + \sum_{i=1}^{3} wr_s + \sum_{i=1}^{3} wu_s + \sum_{i=1}^{3} wi_s$$

Parameters

gr_{asc}= Gross return from crop c in ayacut a during seasons (in million Rs per 1,000 ha), wr_s= WTP for water by household in rural area (in million Rs/MCM), wu_s= WTP for water by household in urban area (in million Rs/MCM), wi_s= WTP for water by industries i in season s (in million Rs/MCM), cw_{asc}= Gross water requirement in MCM per 1,000 ha for crop c during season s in ayacut a, iw_s= Fresh water requirement in MCM by industries in season s, rw_s= Rural water requirement in MCM during season s, uw_s= Urban water requirement in MCM during season, l_{as}= Quantity of water required in MCM for livestock in ayacut a during season, a_{as}= Cultivable land area available in ’000 ha in ayacut a during season s, y_{sc}= Yield of crop c (q/1,000 ha) in season s, s_{ras}= Quantity of reservoir water in MCM available in ayacut a in season s, s_{tas}= Quantity of tank water in MCM available in ayacut a in season s, g_{as}= Groundwater potential available in MCM in ayacut a in season s, t_{bs}= Amount of water transfer from Bhavani basin to Noyyal basin in season s

Resource constraints

The optimization programming problem was justified on the fact that at least some of the resources were limited in supply. The possible major constraints that were included in the present study were land and water.

RESULTS and DISCUSSION

Optimum plan for old ayacut

Once an estimate was made of existing water drawl for domestic purposes, the next logical task was to estimate the likely growth in the future water requirement of the domestic sector. Since the urban

Table 1. Algebraic formulation of the model

Sector	Activity/choice variable	Notation/ index	Explanation
Agriculture	Area under crop ('000 ha)	X_c	c= 1,2,..13 (crops)
Industries	Water requirement (MCM)	I_s	s= 1,2,3 season
Rural population	Water requirement (MCM)	R_{as}	s= 1,2,3 season a= ayacut 1,2
Urban population	Water requirement (MCM)	U_{as}	s= 1,2,3 season a= ayacut 1,2
Livestock	Water for livestock (MCM)	L_{as}	s= 1,2,3 season a= ayacut 1,2
Inter-basin transfer of reservoir water	Transfer of reservoir water from Bhavani sasin to Noyyal basin (MCM)	ITB_s	s= 1,2,3 season
Reservoir water	Utilization of reservoir water (MCM)	SWR_{as}	s= 1,2,3 a= ayacut 1,2
Tank water (MCM)	Utilization of tank water (MCM)	$TSWR_{as}$	s= 1,2,3 a= ayacut 1,2
Groundwater	Extraction of groundwater (MCM)	GW_{as}	s= 1,2,3 a= ayacut 1,2

demand would be expanding due to government priority for drinking water, it was necessary to project the future demands. Projections were usually associated with certain assumptions and past experiences of the region.

In making future domestic water requirement assessment, the immediate task was to predict the growth in population of areas likely to be served by the Bhavani basin. Population data of this basin were collected from the decadal census reports. Annual population growth rates in this basin was estimated using decadal changes in the census data.

The model was first run with existing year (2018-19) water supply level. In the model, the crop activities included were mostly the activities currently practiced. The model also included domestic sector, livestock and industrial sector besides water transfer activities to take care of the surplus water. Constraints included were land by three seasons, irrigation water for three seasons, rural water requirement, urban water requirement, livestock water requirement and industrial water requirement. The model was solved in general algebraic modeling system (GAMS) and optimum plans were obtained. The efficiency of the optimum plans was examined in terms of change in crop enterprises and resource gross margin. The programme results obtained crop-mix in the existing plan and optimum plan I, plan II, and plan III for year 2018-19, 2028-29 and 2038-39 respectively are presented in Table 2.

A perusal of the existing and optimum plan in the study area clearly shows that optimum plan promised significant changes in the land use in different seasons. Due to optimization, only the crops suited for the region under the given resource constraint got included in the respective optimum plan.

It can be seen from the data that the optimums plan suggested lesser area for wet crops than the existing plan. The existing plan consisted of paddy I, paddy II, paddy III, sugarcane, turmeric, banana, cotton, groundnut, and coconut. In the existing plan, paddy I and paddy II were cultivated over 7,174 and 6,004 hectares of land respectively in two seasons viz July-November and December-April. Paddy III was cultivated starting from April-July in 1,750 hectares of land. Groundnut was grown in more than 7,000 hectares ie 7,500 hectares in season III. Sugarcane, turmeric and pulses were grown in more than 1,000 hectares ie 2,650, 1,326 and 1,102 hectares respectively. The other crops namely banana, cotton and coconut were grown in less than 1,000 hectares ie 580, 3,200 and 650 hectares respectively. The existing plan also included inter-basin and intra-basin domestic sector (rural and urban), livestock and industrial sector water supply for three seasons. The cropping intensity was 234.72 per

Table 2. Comparison of existing and optimum plan in old ayacut (area in '000 ha)

Crop	Notation/ index	Programme variable	Existing plan	Optimum	Optimum	Optimum
				Plan-I	Plan-II (2011)	Plan-III (2021)
Paddy I	X1	X1	7.174	6.561 (-8.54)	4.835 (-32.60)	4.544 (-36.66)
Paddy II	X2	X2	6.004	5.334 (-11.16)	4.117 (-31.43)	3.827 (-36.26)
Paddy III	X3	X3	1.750	1.500 (-14.30)	1.500 (-14.30)	1.500 (-14.30)
Pulses	X4	X4	1.102	1.000 (-9.25)	1.000 (-9.25)	1.000 (-9.25)
Sugarcane	X5	X5	2.650	3.000 (-13.21)	3.000 (-17.80)	3.000 (-17.80)
Turmeric	X6	X6	1.326	1.000 (-24.60)	1.000 (-24.60)	1.000 (-24.60)
Banana	X7	X7	0.580	1.000 (+72.40)	1.000 (+72.40)	1.000 (+72.40)
Cotton	X8	X8	3.200	2.000 (-37.50)	2.000 (-37.50)	2.000 (-37.50)
Groundnut	X9	X9	7.500	10.049 (+33.99)	8.798 (+17.31)	8.301 (+10.68)
Coconut	X10	X10	0.650	1.000 (+53.80)	1.000 (+53.80)	1.000 (+53.80)
Gross cropped area	ha	ha	37.79	39.444	35.25	34.172
Net cropped area	ha	ha	16.100	16.100	16.100	16.100
Cropping intensity	ha	%	234.72	244.99	218.94	212.25
Industries I (MCM)	I11	X11	13.05	13.05	14.33 (+10.00)	15.79 (+20.00)
Rural sector I (MCM)	R12	X12	22.17	22.17	24.47 (+10.37)	27.01 (+21.83)
Urban sector I (MCM)	U13	X13	9.06	9.06	9.99 (+10.26)	11.02 (+21.63)
Livestock sector I (MCM)	L14	X14	3.83	3.83	3.64 (+4.96)	3.49 (+8.87)
Industries II (MCM)	I15	X15	13.05	13.05	14.33 (+10.00)	15.79 (+20.00)
Rural sector II (MCM)	R16	X16	22.17	22.17	24.47 (+10.37)	27.01 (+21.83)
Urban sector II (MCM)	U17	X17	9.06	9.06	9.99 (+10.26)	11.02 (+21.63)
Livestock sector II (MCM)	L18	X18	3.83	3.83	3.64 (+4.96)	3.49 (+8.87)
Industries III (MCM)	I19	X20	13.05	13.05	14.33 (+10.00)	15.79 (+20.00)
Rural sector III (MCM)	R20	X21	22.17	22.17	24.47 (+10.37)	27.01 (+21.83)
Urban sector III (MCM)	U21	X22	9.06	9.06	9.99 (+10.26)	11.02 (+21.63)
Livestock sector III (MCM)	L22	X23	3.83	3.83	3.64 (+4.96)	3.49 (+8.87)
Water availability (MCM)			1,245.26	1,245.26	1,157.75	1,157.75
Gross income (million Rs)			2,328.244	2,414.061	2,304.561	2,323.452

cent. The gross income was computed to be Rs 2,328.24 million.

In the optimum plan I (2018-19), area under paddy I, paddy II and paddy III declined from 7,174 to 6,561 hectares, 6,004 to 5,334 hectares and 1,750 to 1,500 hectares respectively. This was a decline of 8.54, 5.33 and 14.30 per cent in paddy I, paddy II and paddy III respectively from the existing plan. Sugarcane increased in optimum plan I from 2,650 to 3,000 hectares with 13.21 per cent increase. Turmeric and pulses declined marginally from 1,326 to 1,000 hectares and 1,102 to 1,000 hectares respectively with decline of 24.60 and 9.25 per cent respectively from existing plan.

As such the area under banana and coconut increased from 580 to 1,000 hectares (42%), 650 to 1,000 hectares (35%) respectively. Area under cotton declined from 3,200 to 2,000 hectares in the third season. The area under groundnut got highly changed in the optimum plan. It competed with cotton in the same season (third season) of old ayacut. But in terms of gross income groundnut crop fetched more gross income than cotton. The cropping intensity in optimum plan I increased from the existing plan (234.72 to 244.99%).

Due to government priority for drinking water for domestic and livestock, water demand did not change in the optimum plan. In industrial cases, government could not reduce the production of industries. So water requirement of industrial needs was also not changed in optimum plan. Hence in optimum plan I domestic sector, livestock sector and industrial sector water requirement level was same as like existing plan. The gross income increased from Rs 2,328.244 to 2,414.061 million. Even with the inter- and intra-basin water transfer, the agricultural sector survived in optimum plan I with marginal decline in

paddy I area (8.5%), paddy II (11.15 %) and paddy III (14.28 %) after water was transferred from agriculture to non-agriculture sectors.

Since an optimum plan I was making use of existing water drawl for domestic livestock and industrial purposes along with agricultural sector, the next logical task was to arrive at an optimum plan for the future years covering the three sectors. So optimum plan II and plan III for year 2028-29 and 2038-39 respectively were worked out to examine the impact of future transfer out of agriculture and choosing appropriate combination of crops.

In optimum plan II (2028-29), the same cropping pattern as witnessed in optimum plan I was noticed except decline in area of paddy I and paddy II ie paddy I declined from 7,74 to 4,835 hectares (32.5%) and paddy II 6,004 to 4,117 hectares (31.4%) respectively. The gross cropped area declined from 31,910 to 28,250 hectares. The cropping intensity declined from 198.36 to 175.47 per cent.

The water requirement for rural and urban sector increased from 93.69 to 103.38 MCM. The industrial water use increased from 39.15 to 42.99 MCM. The water requirement for livestock declined from 11.49 to 10.92 MCM as with the livestock population declined the area under fodder crops was also declined. The gross income declined from Rs 2,328.244 to Rs 2,304.561 million (4.5%). In optimum plan III (2038-39), there was a slight change in cropping pattern from optimum plan II in area under paddy I and paddy II ie paddy I declined from 4,835 to 4,544 hectares and paddy II declined from 4,117 to 3,827 hectares. In optimum plan III (2021), area under paddy I (36.66 %) and Paddy II (36.26%) declined from the existing plan. The cropping intensity also declined from 198.36 to 168.77 per cent from existing plan (10.63%). The water requirement for rural and urban sector increased from 93.69 to 114.09 MCM. The industrial water use increased from 39.15 to 47.37 MCM. The water requirement for livestock declined from 11.49 to 10.47 MCM. The gross income declined from Rs 2,434.430 to 2089.229 million.

Though there was increase in demand for water in non-agricultural sectors, it was noticed in the optimum plan II and plan III that the gross cropped area and cropping intensity had remained almost the same. It would again indicate the sign of bringing in sustainability of the productive capacity of the agricultural sector along with increased water transfer to domestic (93.69 to 114.09 MCM) and industries sector (39.15 to 47.37 MCM) in optimum plan-II and III from optimum plan-I.

The details of resource constraints and their shadow prices of old ayacut optimum plan are shown in Table 3 which represent the marginal value productivities (MVPs) derived from the optimum solution. These shadow prices have been further used to examine the resource productivities and also the direction of resource use pattern among different plans and within the region. Cost and return per unit from different sectors in plan II and plan III are assumed as in plan I keeping other things constant. The marginal value product of land and water in the optimum plans were as follows:

Table 3. Shadow price of resource constraints in old ayacut

Resource		Optimum plan		
		I	II	III
Water season	1	1.400	1.400	1.400
	2	1.167	1.167	1.167
	3	2.143	2.143	2.143

Assumption of cost and return per unit from different sectors in plan II and plan III was as in plan I

It can be seen from the data that land in all seasons in all optimum plans had no shadow price because land remained unutilized due to inadequate availability of water. Farmers who owned wells only to irrigate the land to some extent while the rest kept the land fallow till the release of water from the canal. Since the land was left fallow, the shadow price was zero in all optimum plans.

It was inferred from the optimum plans that if one MCM of water was increased in season I, season II and season III, the gross income over variable cost increased by Rs 1.40, 1.167 and 2.143 million respectively. Water was completely exhausted in all seasons.

CONCLUSION

In case of agricultural productivity, in old ayacut the productivity of water was high in sugarcane (24 kg/mm). One kg of sugarcane was equivalent to 10.26 kg of rice. In old ayacut in the existing plan,

paddy I and paddy II were cultivated over 7,174 hectares and 6,004 hectares of land in two seasons. Paddy III was cultivated in 1,750 hectares of land. Sugarcane, turmeric and pulses were grown in more than 1,000 hectares ie 2,650, 1,326 and 1,102 hectares respectively. The existing plan also included domestic livestock and industrial sector water supply for three seasons. The cropping intensity was 198.20 per cent. The gross income was Rs 2,328.24 million. Regarding shadow price, water was completely exhausted in all seasons. If one MCM of water was increased in season I, season II, season III, the gross income over variable cost would increase by Rs 1.40, 1.167 and 2.143 million respectively. The shadow price per unit of water was Rs.1.40, 1.16 and 2.14 per 1,000 litres in season I, season II and season III respectively.

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