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GROUNDWATER RESOURCES ASSESSMENT AND CONJUNCTIVE USE MODELING FOR MULTICROP IRRIGATION IN PAP BASIN

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ABSTRACT

The concept of conjunctive use of water resources requires judicious planning and policy implementation to utilize the surface and groundwater resources. The concept of integrated hydro-systems management was recognized by the practioners' since early 1970's. Earlier, studies on conjunctive use mostly focused when situations such as water logging and salinization problems were caused by intensive irrigation in many canal commands. But shortages of surface water supplies also necessitated the development of groundwater in many canal commands. In such situation, groundwater can be used along with surface water supplies in a profitable way.

The present study was carried out in Parambikulam- Aliyar - Palar basin, Coimbatore, Tamil Nadu, where the command area is divided into two zones which receive the canal supply once in alternate years. The water demand and available water resources in the study area are evaluated considering surface water and groundwater and rainfall.

The aquifer response and recharge due to rainfall in the PAP basin were studied. The efficiency of canal water delivery system in 4(L) distributory and evaluation of the conjunctive use of available water resources and its optimal allocation with the objective of obtaining maximum net benefits in 4(L) distributory of the Pollachi canal were studied. This paper presents a simple economic- engineering optimization model 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 maximizing net benefits.

INTRODUCTION

Increase in water demand poses new challenges for water resource planners to keep pace with the increase in population. Agricultural production has to be increased which is possible through development of new water resources projects or efficient water management within the existing projects. The concept of integrated hydro-systems management was recognized by the practioners' since early 1970's. Earlier, studies on conjunctive use mostly focused when situations such as water logging and salinization problems were caused by intensive irrigation in many canal commands. But shortages of surface water supplies also necessitated the development of groundwater in many canal commands. In such situation, groundwater can be used along with surface water supplies in a profitable way.

Considering these aspects an attempt has been made to study the conjunctive use planning of water resources in Pollachi canal command of PAP basin (Parambikulam-Aliyar-Palar basin) ,Coimbatore district in Tamilnadu, India (Fig.1).

Materials and Methods

a)Study area

The study was carried out in the canal command area of Parambikulam-Aliyar-Palar (PAP) Irrigation project which spreads in Coimbatore, Tiruppur and Erode districts of TamilNadu. The PAP basin spreads in 2388.72 sq.kms spread over in Coimbatore District of which, one third of the area 822.73 sq.kms is covered with hills and dense forest cover. The basin is surrounded by Cauvery basin on the North and East, Kerala State on the south and West. The water is diverted from west flowing rivers to east by constructing weirs, reservoirs, tunnels, open channels and contour canal etc. to irrigate the drought prone areas of Coimbatore, Erode and Tiruppur districts. The basin is having eight west flowing rivers, six in Anamalai Hills and two in plains. There are 7 canal systems and 3 tanks with total command area of 4.32 lakh ha. The basin is bounded by 10°10’00” to 10°57’20” N latitude and 76°43’00” to 77°12’30” E longitude. The basin has an undulating topography with maximum contour elevation in the plain is 300m and the maximum spot height in the plain is 385m above MSL. The location map of PAP basin is shown in Fig.1

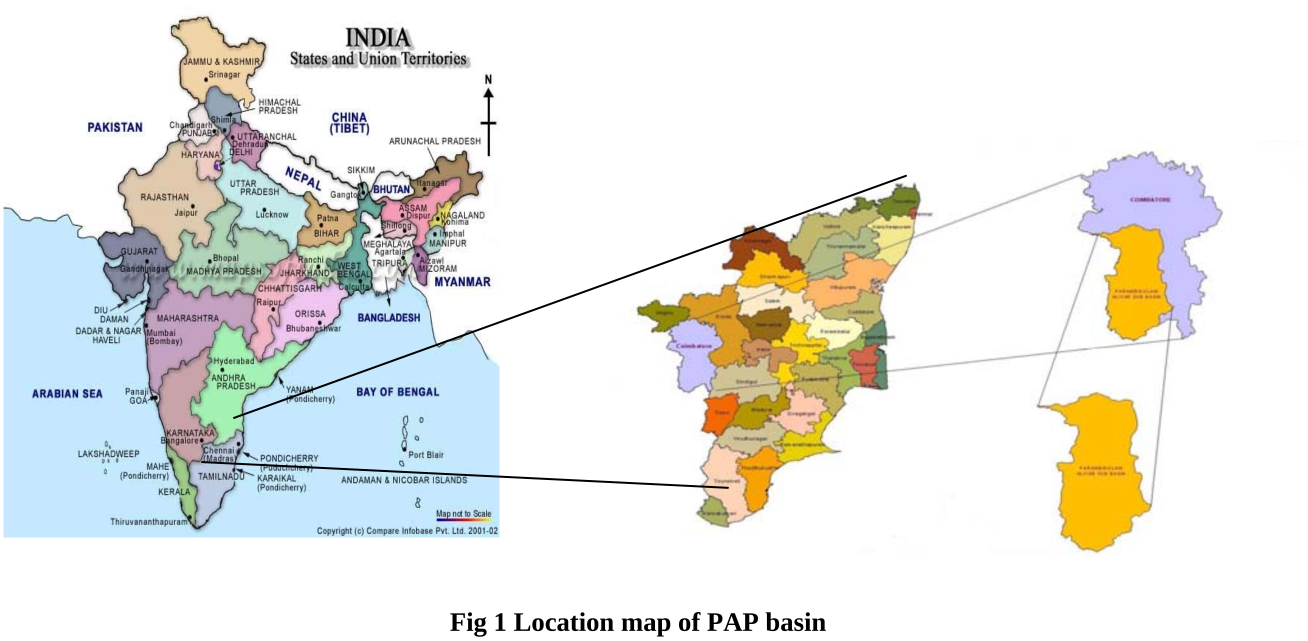

Fig 1 Location map of PAP basin

The project area is situated in tropical monsoon zone having two distinct periods i.e., 1) Monsoon period spanning from June to December and 2) Non-monsoon period spanning from January to May. The maximum monthly rainfall observed during the months of July and October was 148.2 and 153.0 mm respectively. The mean monthly evaporation rate is highest in the month of May i.e. 5.8 mm/day and lowest in the month of November i.e., 3.2 mm/day. The mean maximum temperature of 38.4^{o} C during the month of May was recorded. The mean minimum temperatures varied from 5.4^{o} C to 25.7^{o} C. The wind velocities were highest during the month of June (8.7 kmph) and lowest in the month of November (2.5 kmph).The maximum sunshine hours were recorded during the month of May (10.6 hrs) and minimum during the month of August. The quality of canal water and groundwater gives a picture of water quality scenario that canal as well as groundwater is good for irrigation except for a few wells in the PAP basin.

S.No	Source	EC (dS/m)	pH
1.	Canal	0.735	7.2
2.	Groundwater	0.30-5.19	7.00-8.6

b) Existing Cropping pattern

The soil in the command area is clay loam and is suitable for the cultivation of all crops. The crops grown at present are mainly, Coconut is predominant and Maize, Cotton, Groundnut and Vegetables like Tomato, Brinjal etc are grown in both seasons.

There are two cropping seasons in the area viz., rainfed, during South West monsoon season- (June to Sept) and North East monsoon season (Oct to Dec) and irrigated crops (Feb-May).The study area receives 20 percent of annual rainfall during Jan-May and 80 percent in monsoon season (June-Dec) with occasional long dry spells.

c) Assessment of Irrigation water requirement

The monthly irrigation water requirement for crops grown in command area for the normal year (2008) were made using Aquacrop 3.1 model as shown in Table 1

Table 1 Monthly irrigation water requirements of crops grown in 4(L) distributory

(in mm)

Crop / Month	Coconut	Cotton (R)	Gnut (K)	Gnut (R)	Maize (R)	Maize (K)	Veg (R)	Veg (K)
Jan	106.1			189.8				
Feb	89	65.2		204.2	34		15.7	
Mar	22.5	178.4		72.4	49.9		18.4	

Apr	112.3	170.2			202		136.7	
May	130.3	167.2			193.1		185.3	
Jun	31.6	32.5				36.2	19.1	64.1
Jul	24					39.5		70
Aug	68					39.8		65.7
Sept	49.8		38.5			70.1		114
Oct	6.5		0.0					
Nov	81.4		9.4					
Dec	0.7		74.7	67.2				
Total	**722.2**	**613.5**	**122.6**	**533.6**	**479.0**	**185.6**	**375.2**	**313.8**

(G.nut(K) and G.nut(R) denotes groundnut crop in kharif and rabi season, Veg(K) and Veg(R) represent for vegetable crop in kharif and rabi season and Maize(K) and Maize (R) represent Maize crop grown in kharif and rabi season respectively)

d) Assessment of Groundwater resources

The groundwater resources available during 2000-2010 were calculated using water balance model, are presented in Table 2.

Table 2 Groundwater assessment in 4(L) distributory (**i**n ha m)

	Parameters/Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
A	**Groundwater recharge parameters**											
1	Recharge from rainfall	32.21	29.78	20.85	24.98	27.95	41.84	23.83	45.14	31.17	29.87	35.89
2	Recharge from canal Seepage	0.31	0.36	0.49	0.06	0.60	5.60	9.40	12.94	3.92	10.01	8.68
3	Recharge from canal irrigated fields	3.26	3.54	3.85	1.40	3.61	15.25	20.29	15.24	13.73	19.25	11.61
4	Recharge from well irrigated fields	16.13	23.73	24.15	25.50	15.00	13.78	9.31	8.05	7.26	13.40	16.65
	Total groundwater recharge	**51.90**	**57.41**	**49.34**	**51.94**	**47.16**	**76.48**	**62.83**	**81.38**	**56.08**	**72.52**	**72.82**
B	**Groundwater draft parameters**											
1	Evaporation from	9.35	8.52	10.55	9.36	8.66	7.43	8.16	7.82	6.48	6.42	8.27

	fallow land											
2	Evaporation from groundwater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Soil moisture in unsaturated zone	**11.87**	**9.62**	**25.20**	**6.20**	**15.18**	**3.64**	**9.56**	**19.23**	**15.04**	**10.00**	**11.19**
4	Well draft considering 30% losses	37.63	55.37	56.35	59.50	35.00	32.16	21.71	18.78	16.94	31.26	38.85
	Total groundwater draft	**58.85**	**73.51**	**92.10**	**75.06**	**58.84**	**43.22**	**39.43**	**45.83**	**38.46**	**47.68**	**58.31**
C	Net storage	**-6.94**	**-16.1**	**-42.7**	**-23.1**	**-11.68**	**33.26**	**23.39**	**35.55**	**17.62**	**24.83**	**14.51**

The groundwater balance is the difference between annual recharge minus annual groundwater draft. It is observed that the groundwater draft was more than groundwater recharge during the years 2000, 2001, 2002, 2003 and 2004.This is because the rainfall during these years was less, the canal water supplies were very low (nearly absent) due to which farmers have to depend on groundwater only for crop production.. The groundwater usage during the years 2000-2004 was varying between 113.84 to 186.64 percent of the annual recharge. But, the annual groundwater draft during 2005-2010 varied between 55.20 - 80.08 percent of annual recharge. The safe utilizable groundwater resource for irrigation is taken as 70 per cent of the annual groundwater recharge. This implied that there was little scope for groundwater development which is in conformity with the study report of groundwater department that the area was categorized as semi-critical area (GEC, 2007).

e) Assessment of Canal Water Availability

The number of water release days in the canal system varied from 10-23 days only during 2000-2004 and maximum of 149 days in 2007.

The month wise canal water availability details are presented in Table 3.

Table 3. Month wise details of canal water released into 4(L) distributory from 2000-2010

(in ha m)

Year / Month	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Jun	1.53	0.89	0.24				1.57	7.38			
Jul			1.65					2.49			
Aug		0.00				8.59		4.47		5.21	
Sept		0.26			1.56	12.83	8.60	3.24		5.40	
Oct					1.12	12.42	13.06	4.45	8.66	12.62	9.27
Nov					1.96	6.79	7.06	5.38	8.68	3.27	5.92

Dec	0.74			0.76	1.69	0.44	14.07	7.77	11.29	11.21	
Jan	0.38	2.12	2.98	1.03	0.68	1.05	6.36	6.51	10.60	11.72	10.43
Feb	1.57	2.03	0.45	1.34	2.21	1.47				5.57	
Mar	0.68	1.60	4.01		1.09			1.84			
Apr	2.73	1.87	1.41	0.82			7.24				
May	1.67	1.29	0.29								7.54
Total	**9.30**	**10.1**	**11.0**	**4.0**	**10.3**	**43.58**	**57.96**	**43.55**	**39.23**	**54.99**	**33.16**

f) Conjunctive use model

The linear programming techique has been used to formulate the conjunctive use optimization model, to arrive the optimal allocation of surface and groundwater, to maximize the benefits within the framework of given constraints and designed cropping pattern.

1) Net benefit maximization

The objective is to maximize the net benefit from different crops grown in the command area in different seasons, i.e. monsoon and non-monsoon seasons.

$$Max\ Z_i = \sum_{i=1}^{11}\sum_{j=1}^{3}\sum_{k=1}^{8} a_{ij}kAi_{jk} - \sum_{i=1}^{11}\sum_{j=1}^{3}[C_{ij}{}^{SW} SW_{ij} + C_{ij}{}^{GW} GW_{ij}] \qquad \text{.... (Eq 1)}$$

Where, i = index for sluice of command area; j= index for crop growing seasons; j= 1 for 1st season and j=2 for the 2nd season; k=index for crops, 1, 2, ……., n (number of crops); a_{ijk} = net return for crop k in season j of zone (`/ha); $A_{ijk}$ = area allocated to crop k in season j of sluice i (ha); $C_{ij}^{sw}$ = unit cost of surface water in season j of sluice i (`/ham); SW_{ij} = surface water allocated in season j for sluice (ha m); GW_{ij} = groundwater pumped in season j for sluice i (ha-m); and C_{ij}^{GW}= unit cost of groundwater (`/ha m).

2) Constraints

The objective function is subjected to the following set of constraints.

2.1 Water allocation constraint

The irrigation requirement of all the crops must be fully satisfied during all the seasons from the available surface and groundwater resources. The total volume of irrigation water required in each season depends on the area of each crop and the depth of irrigation water applied to that crop. This depth of irrigation water depends on the crop type, infiltration rate of soil, land slope etc.

$$\sum_{i=1}^{I}\sum_{j=1}^{J} NIR_{ij}\, A_{ij} - \alpha_1(\beta_1 SW_{ij} + GW_{ij}) \le 0; \forall j. \qquad \text{..... (Eq 2)}$$

Where,

α_1 = field water application efficiency

β_1 = conveyance efficiency and

NIR_{ijk} = net irrigation requirement of crop k in season j of sluice i (m).

2.2 Land area constraint

$$\sum_{k=1}^{n} A_{ijk} \leq TA_{ij}; \forall i \,\&\, j \qquad \ldots \text{(Eq 3)} \quad \text{where}$$

TA_{ij} = total cultivable command area of sluice i in season j (ha).

2.3 Water availability constraints

(a) $SW_{ij} \leq TSW_{ij}; \forall i \,\&\, j$ … (Eq 4) where,

TSW_{ij} = total available surface water of sluice i in season j (ha m)

(b) $GW_{ij} \leq TGW_{ij}; \forall i \,\&\, j$ … (Eq 5) where

TGW_{ij} = total available groundwater of sluice i in season j (ha m)

2.4 Hydrologic balance of aquifer

Hydrological balance of the groundwater aquifer will help in keeping the water table at pre-determined level

$$\sum_{i=1}^{10}\sum_{j=1}^{2} GW_{ij} \left\{ \theta_1 SW_{ij} + 10^{-3}\theta_3 E\left(R_{ij}\right) A_{ij} + \theta_2\left(\beta_1 SW_{ij} + GW_{ij}\right)\right\} \leq PMA \qquad \ldots \text{(Eq 6)}$$

Where,

θ_1 = conveyance loss of surface water (fraction) = 0.35

θ_2 = field water application loss (fraction) = 0.3

$\beta_1 = (1 - \theta_1)$ = conveyance efficiency of surface water (fraction) = 0.65

θ_3 = rainfall (recharge fraction) = 0.14

R_{ij} rainfall of sector i in season j (mm)

PMA = permissible annual mining allowance (ha m) and

E = expected operator

The permissible annual mining allowance of the aquifer is determined by

PMA = $\Delta h \times A \times S_Y \times 10^{-2}$ … (Eq 7) Where,

Δh = annual average groundwater table fluctuations (m) and

S_Y = specific yield of the aquifer and

A = total command area (ha)

2.5 Minimum/Maximum allowable area

a. For maximum area

$$A_{ijk} \leq \mu_{ijk}^{\max} TA_{ijk}$$ … (Eq 8)

b. For minimum area

$$A_{ijk} \geq \mu_{ijk}^{\min} TA_{ijk}$$ … (Eq 9) Where,

μ_{ijk}^{max} = factor by which the existing area of crop k in season j of sluice i can be increased and

μ_{ijk}^{min} = factor by which the existing area of crop k in season j of sluice i can be decreased.

2.6 Non-negativity

$$A_{ijk} \geq 0, SW_{ij} \geq 0, GW_{ij} \geq 0, \forall i, j, k$$ … (Eq 10)

Results and Discussion

The conjunctive use model was used to investigate the integrated water use policy options. To understand the present scenario, the model was run for existing cropping pattern with the present condition and then various cases have been investigated for proposed cropping patterns which yielded five alternatives of surface and groundwater utilization. For each scenario, optimal allocations of surface water and groundwater were obtained, considering different options of cropping pattern to arrive at maximum value of the objective function.

Existing cropping pattern

The ratio of canal water to groundwater utilization is in the ratio of 57:43 under the existing cropping pattern (Fig 2). The net benefit obtained was `12734499.65 using a net quantum of 39.23 ha m and 29.2 ha m of canal and groundwater respectively. The contribution from the rainfall to the irrigation requirement worked out to 215.88ha m. The water use efficiency in terms of net returns per ha m water applied under the present scenario worked out to `186095.27/ha m.

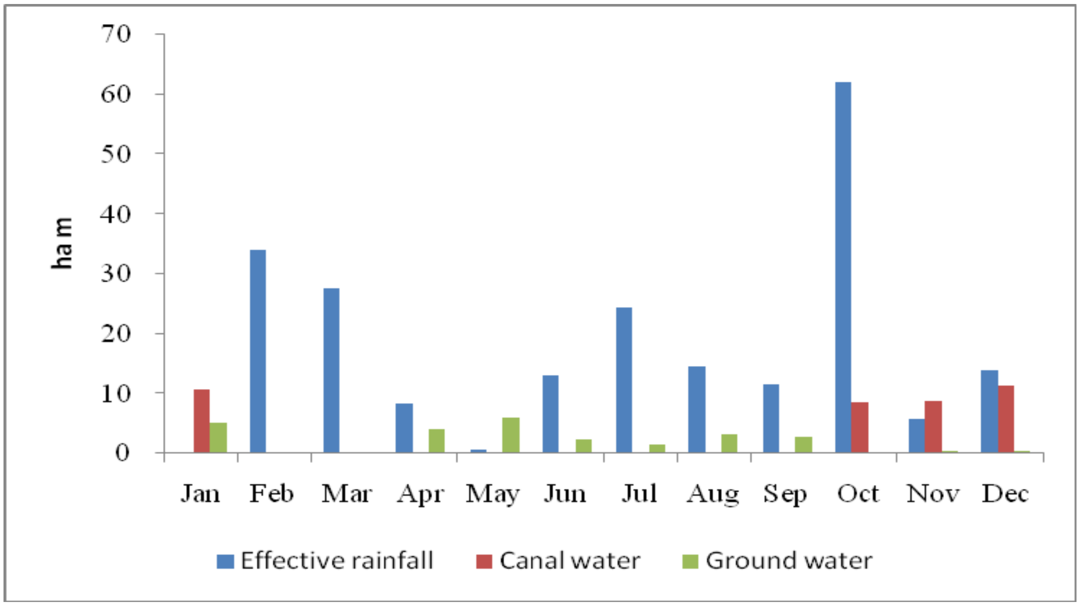

Fig 2 Optimal Water allocation under existing cropping pattern

Proposed cropping pattern

To investigate conjunctive use options, different scenarios for various proposed cropping patterns have been studied. For each scenario, optimal allocations of surface water and groundwater were obtained, considering different options of cropping pattern. Different scenarios of the proposed cropping pattern under the conjunctive use scheme have been formulated, considering percentage of the area under the different crops in the different seasons to arrive at maximum value of the objective function.

Scenario–I The simulation is carried out with existing cropping pattern for maximizing the area under each crop and net benefit. The results of cropping pattern are as shown in Table 4

Table 4. Cropping pattern under proposed scenario I

Name of crop	**Gnut(K)**	**Gnut(R)**	**Cotton(R)**	**Maize(R)**	**Maize(K)**	**Veg(R)**	**Veg(K)**	**Coconut**	**Total (ha)**
Proposed area (ha)	5.00	6.00	13.88	4.02	12.0	6.25	7.35	199.28	253.78

(Gnut(K) and Gnut(R) denotes groundnut crop in kharif and rabi season, Veg(K) and Veg (R) represent for vegetable crop in kharif and rabi season and Maize(K) and Maize (R) represent Maize crop grown in kharif and rabi season respectively)

The month wise optimal canal water and groundwater allocation under proposed cropping pattern scenario I are shown in Fig 3.

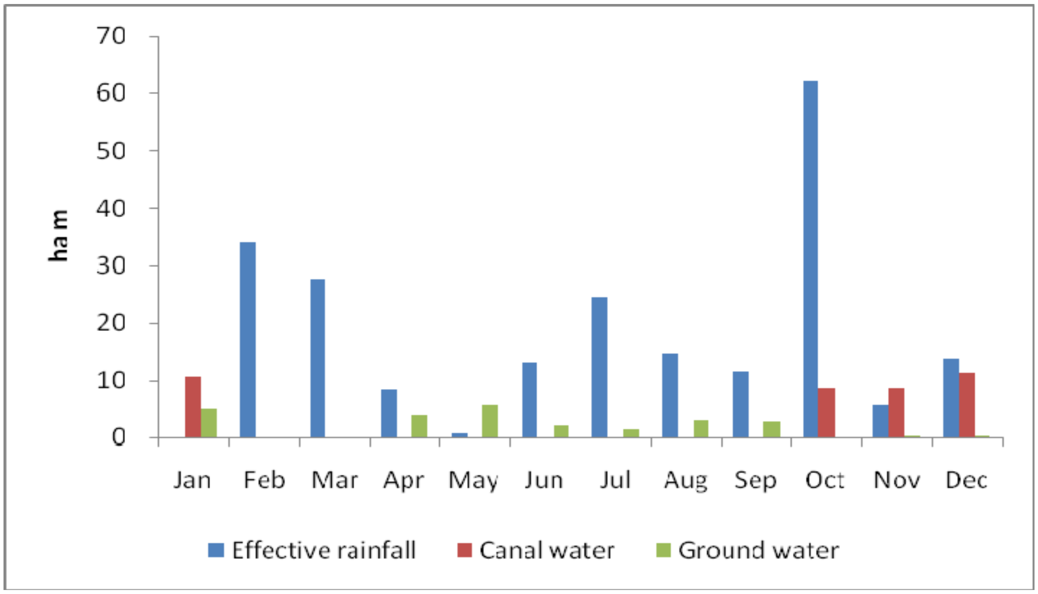

Fig 3 Optimal allocation of surface and groundwater utilization in proposed cropping pattern Scenario I

The results obtained propose an increase in vegetable area in Pre-monsoon season from to 3.29 ha to 6.25 ha and vegetable area in post monsoon season from 4.02 ha to 7.35 ha from 39.2 ha-m surface water and 24.9 ha-m of ground water utilization and net benefit of. `13504549.65 have been obtained with an increase of 6.1 percent over the existing cropping pattern. The surface and groundwater utilization pattern in proposed scenario I is in the ratio of 61:39. The water use efficiency was worked out as `210646.5/ha m.

Scenario II

The simulation has been carried out with Coconut area (199.3ha) as constant with cotton in pre-monsoon season, vegetables in both seasons resulted in the area under Cotton, Vegetable crop during kharif and Vegetable crop during rabi season as 12ha, 15.25ha and 27.25ha respectively.

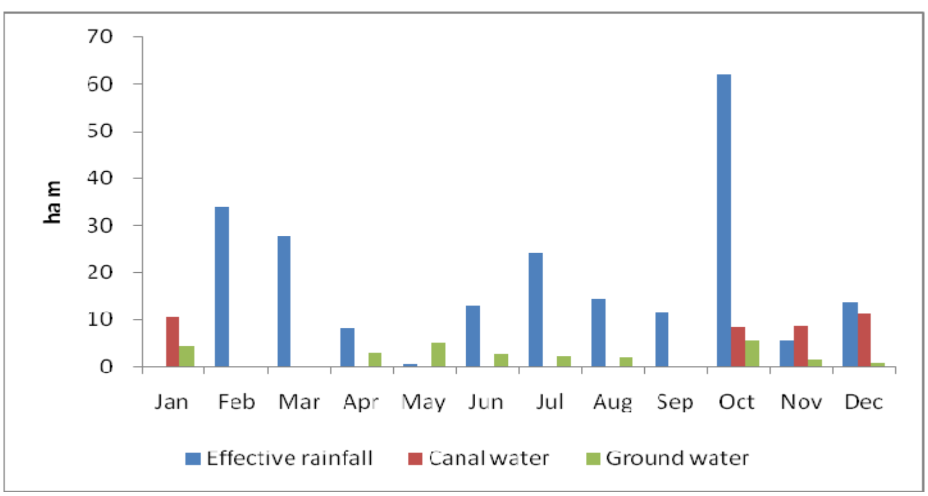

Fig 4 Optimal allocation of surface and groundwater utilization in proposed cropping pattern Scenario II

The surface water utilization as constant but groundwater utilization as 28.44ha-m under the scenario II (Fig 4) indicated reduction in water utilization is 12.83 percent compared to existing pattern. The net benefit of `13931388/ was obtained with canal water and groundwater utilization in the ratio of 58:42.The water use efficiency was worked as ` 205872.44/ha m.

Scenario III The area under coconut has been kept constant as it is perennial crop, the area under vegetables in both Pre and post monsoon periods as 27.25 and 27.25 ha respectively.

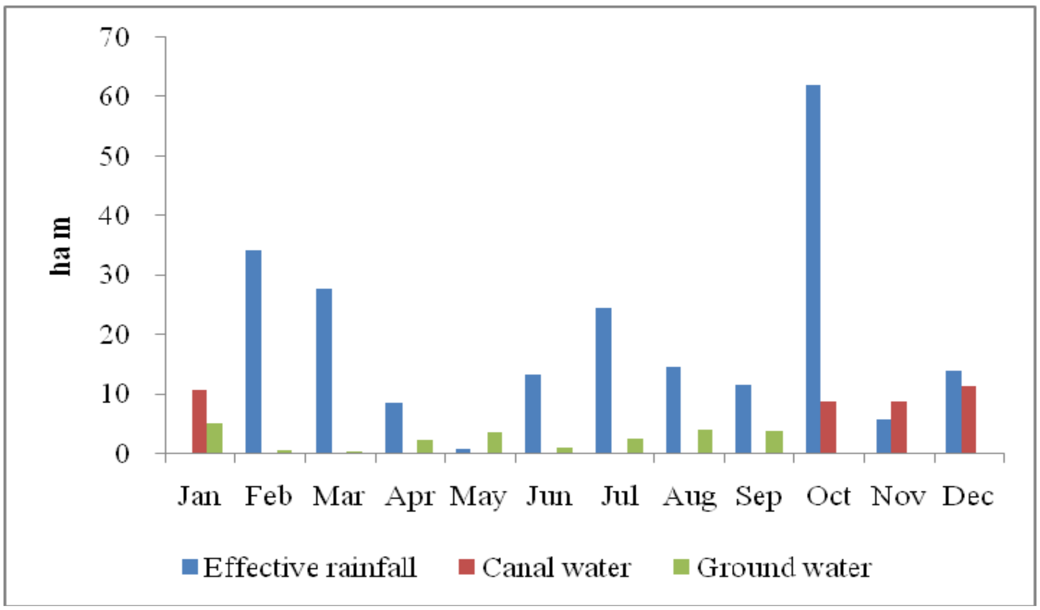

Fig 5 Optimal allocation of surface and groundwater utilization in proposed cropping pattern Scenario III

The ratio of canal water to groundwater utilization is in the ratio of 64:36 under the Scenario III (Fig 5). The net benefit obtained was `14244036/ using a net quantum of 39.23ha m and 22.24 ha m of canal and groundwater respectively. The contribution from the rainfall to the irrigation requirement worked out to 215.88 ha m. The water use efficiency in terms of net returns per ha m water applied under the present scenario worked out to `231723.38/ha m.

Scenario IV

The ratio of canal water and groundwater utilization is in the ratio of 20:80 under scenario IV (Fig.6). The excess of groundwater mining will lead to decline in water table. (more than 70 percent of allowable mining). The net benefit has been worked out as `12691331 with a reduction in benefit by 6.02 percent over existing pattern. The water use efficiency in terms of net water applied under scenario IV worked out to be `64373.98/ha m.

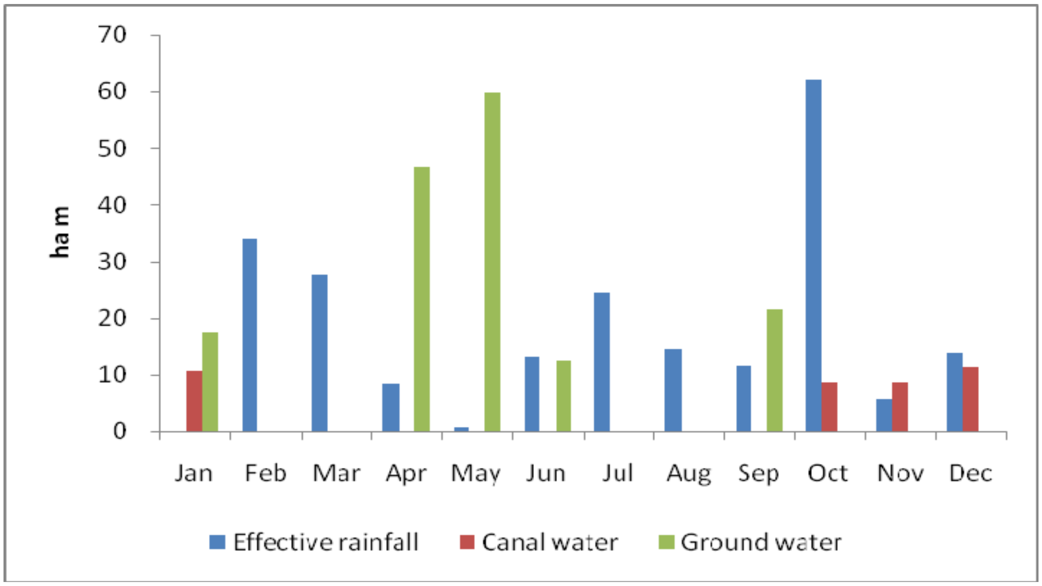

Fig 6 Optimal allocation of surface and groundwater utilization in proposed cropping pattern Scenario IV

Scenario V The area under coconut remaining constant with introduction of another horticultural crop, banana was worked out. The water requirement of banana is 1350 mm/ha with net benefit of `99000/ha.

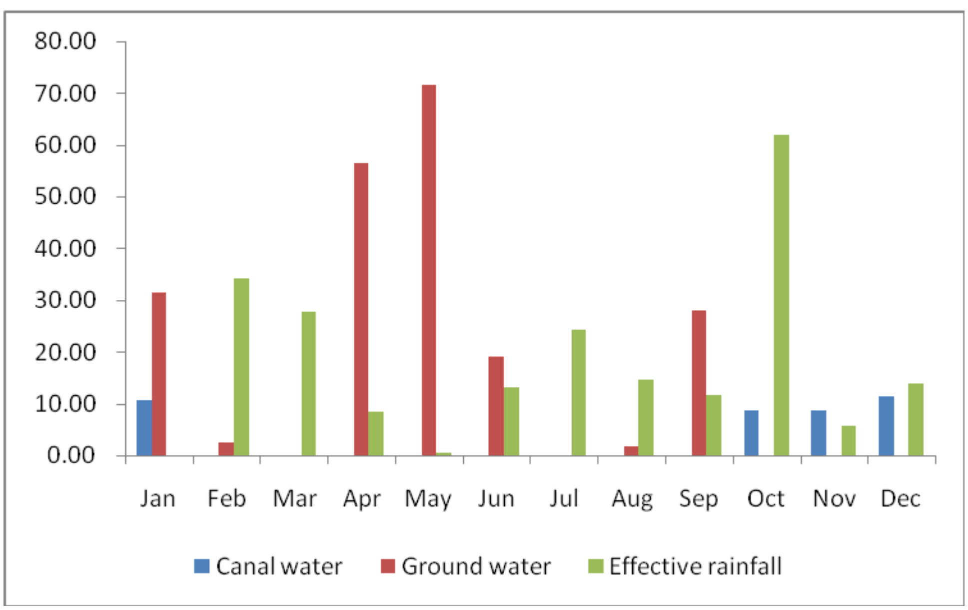

Fig 7. Optimal allocation of surface and groundwater utilization in proposed cropping pattern Scenario V

The results obtained from simulation showed that canal water and groundwater applied are in the ratio of 16:84. The net benefit of `13862536 was obtained with 8.86 percent more over the existing cropping pattern. The water use efficiency in terms of net water applied worked out to be `55447.93/ha m.

Table 5 Optimal allocation of surface and groundwater under different scenarios along with net benefits

	CW, ha m	GW, ha m	Net benefit, `
Existing scenario	39.23	29.2	12734499
Scenario I	39.23	24.87	13504549
Scenario II	39.23	28.44	13931388
Scenario III	39.23	22.24	14244036
Scenario IV	39.23	157.92	12691331
Scenario V	39.23	210.78	13862536

The scenario III (coconut+Veg1+ Veg2) i.e., was found most appropriate with highest net benefit of `14244036 and considering optimal surface water and groundwater allocation in the ratio of 64:36 and groundwater constraint i.e., allowable mining limited to 70 percent of annual recharge.

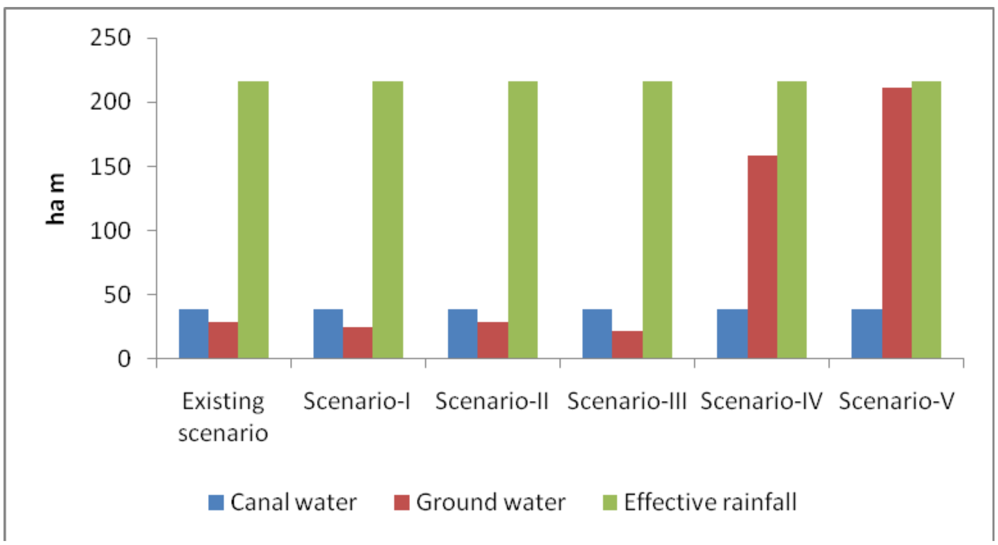

Fig 8. Optimal allocation of canal water and groundwater under different scenarios

The different crop combination scenarios led to the following ratios of canal water and ground water utilization and water use efficiency as shown in Table 6.

Table 6 Ratios of canal water and groundwater allocation and respective water use efficiencies

Scenario	CW:GW	WUE, `/ha m
Existing scenario	57:43	186095.3

Scenario I	61:39	210646.5
Scenario II	58:42	205872.4
Scenario III	64:36	231723.4
Scenario IV	13:87	64373.98
Scenario V	16:84	55447.93

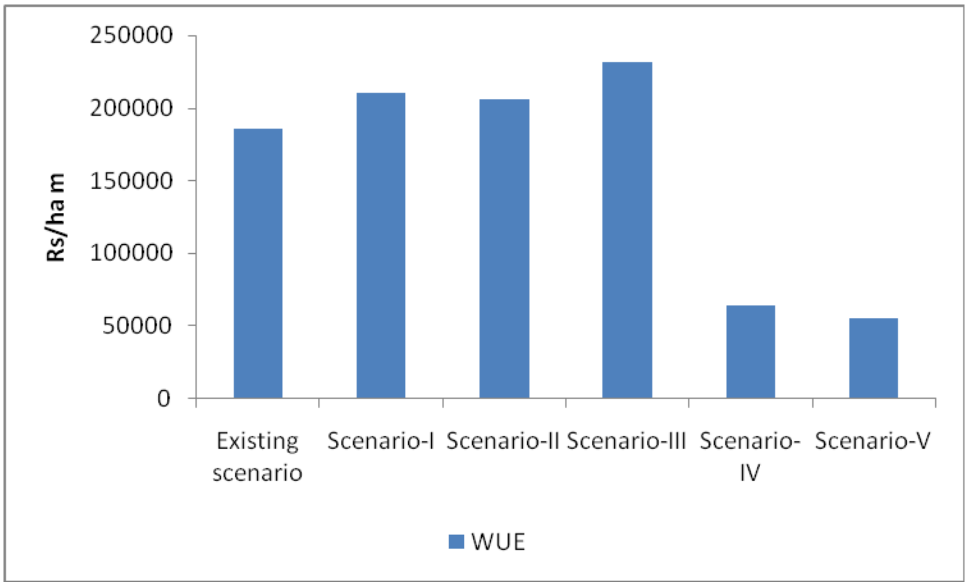

Fig.9.Water Use efficiencies under different scenarios

The water use efficiency was found to be highest under scenario III (Fig 9) when compared to other scenarios under permissible groundwater mining.

The optimal utilization of canal and groundwater resources under different scenarios was worked out using linear programming. The optimal allocation of canal and groundwater in the ratio of 64:36 gave the maximum benefit of `142.44lakhs with coconut (199.28 ha) and bringing the remaining area under vegetables (27.25 ha) in two crop seasons. An increase in benefit of 24.5 percent could be visualized over the existing cropping pattern. The overall water use efficiency of ` 231753.40 could be obtained under the proposed cropping pattern against ` 186095.3 of existing cropping system. This option brought out safe and sustained groundwater usage of less than 70 percent, of annual recharge of groundwater.

Even though the groundwater irrigation is costlier, it offers control over irrigation and helps save input investments. Their systematic integration in canal irrigation system raise the productivity of the system as a whole, extend the area served, and helps in preventing waterlogging and increasing the natural recharge. But the success of any conjunctive use of surface and groundwater lies in the improved new system management per se. these improvements may require changes in the infrastructure but are more a question of building technical capacity, adopting organizational and institutional frame work for more efficiency and improving information and communication systems.

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