Is the current land use pattern in crop agriculture is sustainable in the Bhavani Basin of Southern India?: Application of a Bio-economic model

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Is the current land use pattern in crop agriculture is sustainable in the Bhavani Sub-Basin of Southern India?: Application of a Bio-economic model

Abstract

Efficient and sustainable utilization of resources, particularly land and water resources for agriculture have occupied the centre stage in the economic agenda of a nation. The regional resource availability and the biotic, abiotic and socio-economic constraints are largely varied in the any crop production system of that region. The integration of sustainable resource use with the production programs and income as objectives of farming thus, leads to a multiple objective-planning framework. Attaining sustainable increase in agriculture production by considering the biophysical variability of the region without affecting the natural resources base is therefore very important to achieve food security for the growing population in a developing country situation. The current study is to develop appropriate land use pattern in crop agriculture for sustainable land and water use to the agricultural development in the Bavani Basin of western zone of Tamil Nadu state in southern India, using a multiple goal linear programming approach. Bhavani basin in the western zone of Tamil Nadu - one of the most diversified in bio physical features, was evaluated in this study. The land use model employed in the study following the bio-economic model by Shiferaw and Holden, (2003) who incorporated the important variations in the biophysical system (land and soils) and market characteristics. This study traced the alternative cropping pattern which would maximizes the farm net income at a relatively lower water requirement, lower land requirement (hectare days to ensure relatively more fallow period to lower land exhaustion rate) and that would lower the environment damage in-terms of lower Environmental Impact Quotient (EIQ) with the given land and ground water availability of each identified ten homogeneous land units beside the length of growing period determined on the basis of quantum and distribution of rainfall and temperature. The major biophysical factors considered beside the land availability, ground and surface water availability were; crop suitability for the particular soil type, crop sequence and climatic variations and these factors were specified as constraints in the land use model. The input data for the model were collected from the sample respondents in the delineated homogeneous land units. The actual water availability for each standard week (t) was estimated after adjusting the effective rainfall received during the period of crop stand from the total water requirement of each crop activity.

The land use model estimats revealed the possibility of increasing the crop income from the current level of INR 6.14 billion to INR 8.25 billion annually. This alternative crop plan also helped to reduce the area under high water consuming crops in water deficit areas.

INTRODUCTION

Economic development and human welfare largely depend on optimum utilization of natural resources. There exists a wide spatial diversity in quantity and quality of land and water resources available and their efficiency in use for agricultural and non-agricultural purposes. Efficiency and sustainability paradigms have therefore occupied the centre stage in the economic agenda of a nation. A large proportion of India's land shows clear evidence of advanced and continuous degradation, threatening to undermine the capacity to increase food production and alleviate rural poverty (Abrol, 1994). Despite the critical situation, the increase in population led to decline the per capita availability of net sown area from 1.76 ha in 1950-51 to 0.11 ha in Tamil Nadu in India in 2007-2008. On the other hand, the water availability for agriculture from both surface and ground water sources was not able to meet the increasing demand by the changing cropping pattern and climatic variability. Annual internal renewable water resources in India fell by 652 cubic meter (cum) per capita in about 12 years i.e., from 1896 cum in 1988 to 1244 cum in 2000 (HDR, 2000). The ground water estimation committee (1994) estimated the annual replenishable ground water potential to be 431 bcm and the ultimate irrigation potential in terms of area was estimated to be 80.38 mha. During the period from 1984-85 to 1998-99, the number of dark[1] blocks (administrative unit consists of few villages) had increased from 253 to 428 at the national level. If this trend continues, the number of overexploited blocks would be doubled over a period of every twelve and half years (Swaminathan, 2002). In the State of Tamil Nadu the groundwater was over exploited in 54 bocks out of a total of 385-blocks which spread over in 16 districts (CWC, 2000).

The integration of sustainable resource use with the production programs and income as objectives of farming thus, leads to a multiple objective-planning framework. Attaining sustainable increase in agriculture production by considering the biophysical variability of the region without affecting the natural resources base is therefore very important to achieve food security for the growing population in a developing country situation. In such a situation, there is an urgent need to identify concrete policy measures that would permit a simultaneous improvement of agricultural production and conservation of natural resource base especially land and water resources.

Tamil Nadu state in southern India is divided into seven agro climatic zones based on rainfall distribution, irrigation pattern, soil characteristics, cropping pattern, ecological and social characteristics. Among these seven zones, the Western zone consisting of Coimbatore and Erode districts **covering Bhavani basin** occupies 12.03 per cent of the state's geographical area and 11.45 per cent of the state's net sown area. This zone accounts for close to 15 per cent of degraded land in the State. The western zone receives the lowest annual rainfall of 700 mm compared to the 959 mm for the State. Besides, well irrigation is the predominant source of irrigation in this zone accounting for about 53 per cent of total irrigated area. The depth of the water in this zone however, has fallen between 6 meters and 49.3 meters in the rainfall deficit years when the annual

[1] Dark block are were the groundwater extraction is more than recharge

rainfall was around 450 mm. Due to poor maintenance and reduction in storage capacity of tanks, ponds and other small reservoirs also affect the groundwater recharge in this zone. The over extraction of groundwater and inefficient use of irrigation water for crops also leads to faster reduction in groundwater table. The current study therefore aims to answer the following question confronting the stakeholders in the region namely:

1. What would be the optimal land allocation to different crop activities that will maximize the net farm income with the available land, water and environmental resources in the region?

The overall objective of the study is to develop appropriate land use pattern in crop agriculture for sustainable land and water use to the agricultural development in the Bhavani basin of the western zone of Tamil Nadu.

2. METHODOLOGY

In India, private property right for land will leads to over exploitation of land, water other resources which causing spatial and temporal damages. This study is indent to identify the land allocation pattern to the different crops and how the different resources or inputs like labour, water and credit are judiciously used to reach the maximum net return with the available production activities in the context of sustainability. In order to achieve the sustainability in land and water resources use, the spatial variability on bio-physical characters must be considered. This would be achieved by identifying the homogeneous land which having same bio-physical features of surface water availability, ground water status and climatic feature like temperature, rainfall and Length of Growing period (LGP).

Land Use Model

Land use studies dealing with the future prospects are generally of two types - predictive and explorative. The explorative land use studies focus more on defining the range of developmental possibilities at different scale (Van Ittersum *et al*., 1998). These studies emphasized the biophysical possibilities, assuming that socioeconomic constraints could be managed in the long run (Van Keulen et al., 2000). Bio-economic modeling (BEM) approach was used to analyze the combined effect of land degradation, population growth, market imperfections and increased risk of drought on household production, welfare and food security (Holden and Shiferaw, 2002). They used dynamic non-separable household model which maximized the household welfare.

The land use model employed in this study following the bio-economic model by Shiferaw and Holden, (2003) which incorporated the important variations in the biophysical system (land and soils) and market characteristics. Loborte et. al.(2009) developed and evaluated the methodology for exploring the lands use option at sub national level to improve the scientific basis for lands use planning which provided the facilities for land evaluation for resource availability, scenario construction and land use optimization. Following the methodology this study would trace the alternative cropping pattern which maximizes the farm net income with the given land and ground water availability of each identified ten homogeneous land units (HLUs). The land and water availability of the each HLUs were taken as constraints. The actual crop water availability for each standard week (t) was estimated after adjusting the effective rainfall received during the period of crop stand from the total crop water requirement of each crop activity.

Input-output coefficients

The input-output coefficients for the land use model were estimated from a sample of 330 farm households spread in 22 villages covering all identified 10 land units. The distribution of the sample households among the 10 HLUs is presented in Table 1.

Table 1 Distribution of Sample village in different land units

Land Unit Classification	Land units		Geo area		Selected villages		
	ID	Number	area (ha)	% share	CBE	Erode	WZ
Non ayacut critical average LGP	0CA	1	128370	10.92	1		1
Non ayacut over-exploited average LGP	0OA	2	303836	25.84	2	3	5
Non ayacut –semi-critical- average LGP	0RA	3	182576	15.53		3	3
Non ayacut semi-critical good LGP	0RG	4	32893	2.80		1	1
Non ayacut safe average LGP	0SA	5	46785	3.98		1	1
Ayacut critical average LGP	1CA	6	39362	3.35	1		1
Ayacut critical good LGP	1CG	7	36016	3.06	1		1
Ayacut over exploited average LGP	1OA	8	78946	6.72	2		2
Ayacut semi-critical average LGP	1RA	9	280800	23.88	2	3	5
Ayacut safe average LGP	1SA	10	46061	3.92		2	2
Total map area			1175645 (75.40)	100	9	13	22
Reserved Forest (RF)			387625 (24.60)				
Total Geographical area			1563270 (100)				

The land unit 0OA- Non ayacut over exploited with average LGP less than 70 days of LGP without surface water facility is spread over 3.03 lakh ha which constituted 25.84 per cent of the total geographical area of the western zone (11,75, 645 ha which excluded the reserved forest area). This is followed by the land unit 1RA- Ayacut semi-critical with average LGP with surface water facility which occupied about 2.80 lakh ha (23.88 per cent of total area).

The field survey was conducted during 2006 and the farm data were collected on recall basis for the normal year (2004-05). Primary data covering land use, cropping pattern, cultivation practices, irrigation, depth of water table in the tube and open wells, well output, human labour, animal and machine power used, chemical and other inputs used, crop outputs, input and output prices paid and received by farmers respectively and other household and farm details were collected from the selected sample farms through a well-structured pre tested questionnaire. The input use and outputs obtained for different crop activities were varying for each of the HLUs and over seasons. The inputs required for cropping activities such as fertilizer (N, P and K nutrients), water, pesticides and other expenses on labour, bullock and

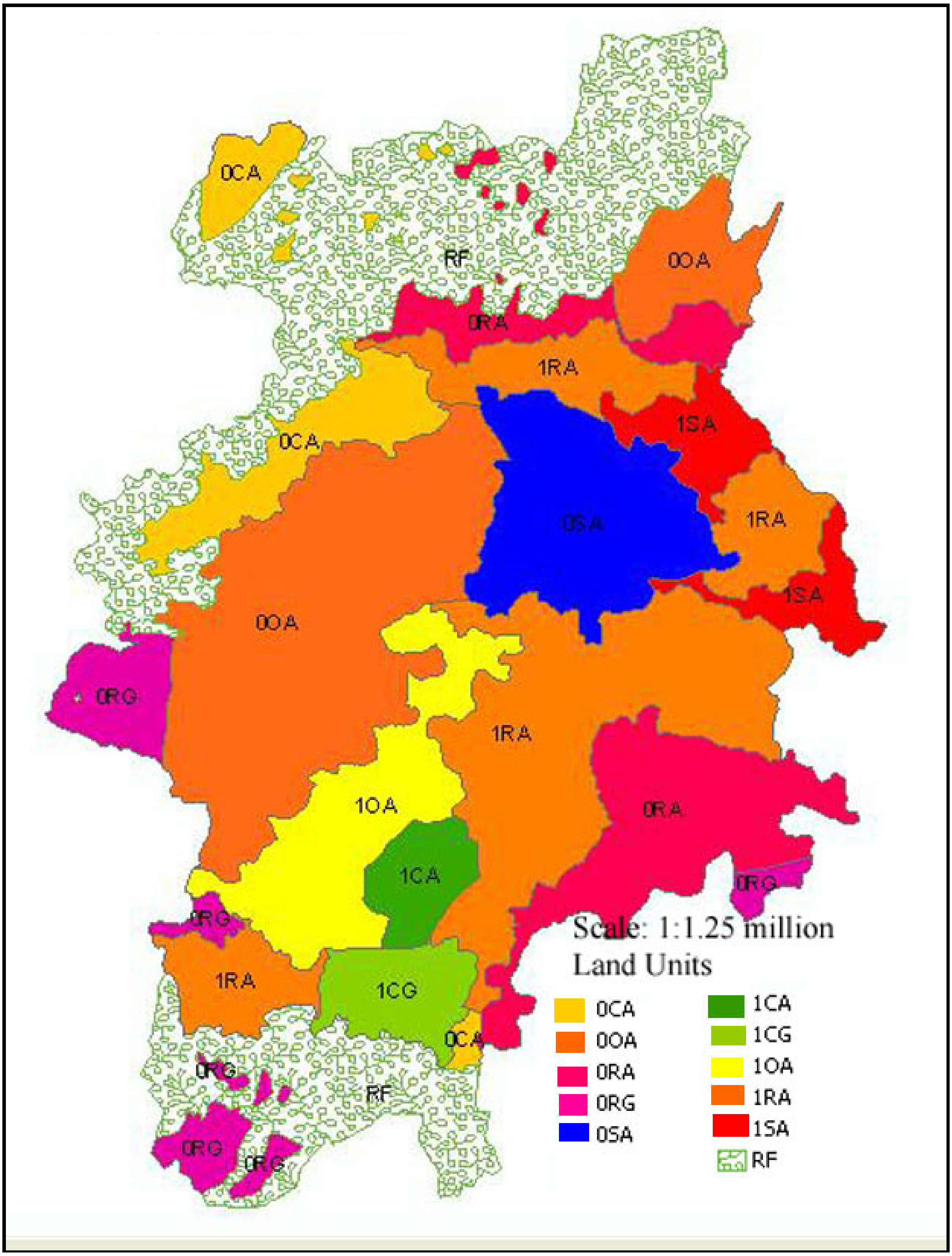

Figure 1: Homogenous land units of Bhavani basin in Western zone of Tamil Nadu, southern India

Note: The land units are designated with three character codes. The first character 1 or 0 indicates ayacut (irrigated) and non-ayacut (un-irrigated); the second character O, C, R & S refer to grounds water categories namely; over-exploited, critical, semi-critical and safe, respectively; the third character A or G represents Length of growing period with < 70 and >70 Days, respectively.

machine power were considered. From this data set, cost (operational cost) and returns were estimated for the crops raised in the identified HLUs.

2.2 Static Land Use model

The indices used in the land use model are given in Table 2.

Table 2 Indices and Abbreviations used in defining Land Use Model

Index	types	Characters considered
z	Homogenous land units (HLU) (10 HLUs)	LGP, ground water, surface water availability and length of growing period used to delineate HLUs
t	Time (52 standard weeks)	Land and ground water availability for each HLU were estimated for each standard week.
c	crops (26) 19 irrigated crops (i) 7 rainfed crops (r)	Crops in the different HLUs: The composition of different crops in vary spaciously depending on the agro-climatic suitability, marketing feasibility and technology availability for the region. However, 26 crops covering cereals (5), pulses (1), oilseeds (3), fiber(1), tuber (1), sugar crop (1), spices (2), fruits (1), vegetables (3) and narcotics were considered in the model. Cereals: Kuruvai and samba rice, maize (I & r) finger millet and grain sorghum (i & r), fodder sorghum (r) Pulses: Pulses (i & r) Oilseeds: groundnut (I & r), gingelly (i& r) and sunflower Fiber: Cotton (I & r) Fruits: banana; Tuber: tapioca Sugar: sugarcane; Spices: turmeric and chilly Vegetables: onion, Brinjal, tomato Narcotics: tobacco (Note: Trees :coconut and other tree cropped area excluded from the land availability)

Note: I - irrigated; r- rainfed

2.2.1 Objective Functions: Maximizing Net Income

In this study a regional level explorative land allocation model was developed which would maximize net income from crop enterprises in the region. Income from each crop activity was the major factor that would determine the selection of crops. Thus, the objective function was maximization of net income from crop enterprise in the model.

$$\text{Max } cinc = \sum_{z}\sum_{c} NI_{z,c} \text{ x } vArc_{z,c}$$

$$NI_{z,c} = GI_{z,c} - opC_{z,c}$$

Where

$cinc$: Crop enterprise net income

$vArc_{z,c}$: The level of crop activity ‘c’ in HLU ‘z’

$GI_{z,c}$: Gross revenue from crop activity ‘c’ in HLU ‘z’

$opC_{z,c}$: Operational cost for crop activity ‘c’ in HLU ‘z’ and

$NI_{z,c}$: Net crop income per hectare from crop activity (difference between the gross revenue and operational expenditure of crop production). The operational cost per ha did not include the fixed costs and land rent.

2.2.2 Constraints

The net arable land availability (excluding area under coconut and other tree crops) and the availability of ground water were considered as constraints besides the fodder production in the model. The surface water feature was incorporated in the HLU classification through GIS technique.

Agricultural Land Area: $$\sum_c \sum_t ac_{zt} \text{ x } vArc_{z,c} \leq a_z$$

Where

ac_{zt} : The land area requirement for each crop 'c' in HLU 'z' at time period 't'. The land requirement was derived considering the crop suitability and sowing season conditional matrices derived from the discussion from the experts and secondary sources.

$vArc_{z,c}$: The level of crop activity 'c' in each HLU 'z' and

a_z total land availability in each HLU 'z' after adjusting the area for perennial trees like coconut and other trees not included as crop activities.

Water availability constraint: $$\sum_c wnn_{z,ic} \text{x } vArc_{z,ic} \leq \sum_t tw_{zt}$$

Where

$Arc_{z,c}$: The level of crop activity 'c' in each HLU 'z'

$wnn_{z,ic}$: The total actual water need for irrigated crop activity 'ic' in each HLU 'z'. The water need was calculated considering the availability of weekly effective rainfall and ground water availability and recommended water requirement of each crop activity.

tW_{zt} : zone wise water availability for standard week t, considering both surface and groundwater availability for each HLUs for each standard weeks.

Actual Crop Water Requirement

The actual water needs for each crop was calculated considering the moisture availability through the effective rainfall during the stand of the particular crop. The equation is given as

$$wnn_{z,c} = Wr_c - effRf_{zc}$$

where

$wnn_{z,c}$: Actual water required for each crop 'c' in HLU 'z'

Wr_c : recommended water requirement for crop 'c' and

$effRf_{zc}$: Total soil moisture available through effective rainfall for zone'z' for crop 'c'.

Effective Rainfall

The moisture availability through effective rainfall ($effRft_{zt}$) for each HLU 'z' in time period 't' was calculated by adding the daily rainfall in each HLU 'z' (more than 2.5 mm and less than 50 mm per day). It was assumed that only 60 per cent of total rainfall reaches soil profile and the remaining 40 per cent drained out through runoff and seepage. Then, the crop wise moisture availability through effective rainfall was estimated by adding these for respective weeks of crop stand in that location. The equation is as follows:

$$effRf_{z,c} = \sum_{t,c} effRf_{z,t}$$

Bio-physical Constraints: Soil Series and Crop Suitability

Soil quality based crop suitability was incorporated in each HLU, based on the soil characters as constraint. The crop suitability constraint is specified as follows:

$$Arc_{z,c} \text{ x } Bp_{z,c} \leq Suit_{z,c}$$

where

Arc_{zc} :decision variable; area to be allocated for crop 'c' in zone 'z'

BP_{zc} :Crop 'c' can be cultivated in zone 'z' as 1 and 0 other wise; included as land suitability matrix

$Suit_{zc}$: total area suitable for crop 'c' in HLU 'z'

2.3 Land and Water Resources Efficiency Analysis

Cropping Intensity (CI) was calculated as the percentage of gross cropped area (GCA) to the total cultivable land area available for cultivation (LA).

$$CI = \frac{GCA}{LA} * 100$$

Based on Subbian et al. (1999) Cumulative Land Utilization Index (CLUI) was calculated by summing the products of land area planted to each crop and the actual duration of that crop in weeks and dividing this by the total cultivable land area times weeks.

$$CULI = \frac{\sum_{i=1}^{n} a_i d_i}{LA * 52} * 100$$

where

CLUI - Cumulative land utilization index in per cent

a_i - area occupied by the i^{th} crop

d_i - weeks that i^{th} crop occupied

n - total number of crops

LA - total cultivatble land area available in a year

The CLUI would reach the maximum of 100 per cent when all the available land area was occupied by different crops throughout the year. Lesser CLUI with low level of water use that could generate maximum net income is preferred for land and water resources sustainability.

Water Use Efficiency (WUE) is the ratio between the total net return realized from the irrigated crop to total water used by the crop plan.

$$\text{WUE} = \frac{NI}{WU}$$

Where

WUE - Water use efficiency rupees per thousand liter of water

NI - Total net income realized from the irrigated crops in the optimal plan in INR

WU - Total water used by the crop plan in thousand liters

Considering the complexity of the present static land use model for 10 different HLUs, the General Algebraic Modeling System (GAMS 22.9, 2009) was used for developing the land use model. The model consisted of 260 (10x26) crop activities with 520 (10x 26 x 2) equations each for land and water resources, 260 (10x24) equations for crop suitability constraints. Thus, totally 260 activities and 1040 constraints besides the non-zero equations were used in formulating the land use model and solved using GAMS.

3. Results and Discussion

The results and discussions included; the description the land area availability, delineation of the homogenous land units, followed by the model results.

The Bhavani basin of western zone of Tamil Nadu was divided into 10 agro-ecological HLUs by overlaying the three spatial attributes namely; (i)availability of surface irrigation, (command area map); (ii) ground water categorization based on the extraction levels of ground water; and (iii) the climatic feature (by developing the length of growing period - LGP) using GIS overlay technique and the same is presented in the map (Figure 1).

3.1 General Characteristics of the sample farms identified in the HLUs

The farm and famer's general characters such as; farm size, family size, main and secondary occupation, family labour availability for farm operation were analyzed from the sample data collected for each of the HLUs. The average farm size was 0.72, 1.64 and 4.95 ha for marginal, small and medium to large size farm categories, respectively. The marginal and small farmers constituted about 59 per cent of the total number of sample operational holdings in the Bhvani basin of western zone in Tamil Nadu and they operated only 15 per cent of the cultivable area. The average family size in different farm size groups ranged from 4.00 (marginal farms) to 4.68 members per family (in large farms) in which children constituted 15.19 per cent of the family size. Male members engaged in agricultural operations constituted 73 per cent, whereas, two thirds of the females were engaged in the agricultural operations.

3.2 Operational Expenditure for Major Crops under Homogenous Land Units

The operational expenditure for cultivating major crops in the western zone was estimated from the sample farms (Table 3) to derive the net income per hectare realized from each crop in each of the HLUs. The operational expenditure includes all the paid out cost on inputs except the fixed cost. The results indicated that the operational cost was the highest for sugarcane (INR 59484 per ha.) followed by INR 58385, INR 51864, INR 43893 and INR 28528 per ha for banana, turmeric, tapioca and groundnut, respectively. The cultivation expenses of kharif paddy was INR 19027 while for rabi paddy it was INR17840 per ha. Among different homogenous land units, farmers incurred marginally higher operational expenses in ayacut land units (irrigated) such as; 1CA, 1OA, 1RA, 1SA and ICG for most of the crops; this may be due to higher use of inputs to achieve the targeted yield with the limited resources.

Table 3 Operational Expenditure for cultivating different crops under different land units

(INR/ha)

Crop	Non Ayacut Land units						Ayacut Land units						ALL	CV %
	0CA	0OA	0RA	0RG	0SA	All	1CA	1CG	1OA	1RA	1SA	All		
PADk	17900	18683	18579	19597	17600	18472	18300	22800	19560	18248	19002	19582	19027	7.76
PADr	19248	18579	16579	16579	16579	17513	19001	16002	19002	18579	18248	18166	17840	7.01
RAG	6570	6800	5740			6370	6300			5800		6050	6242	7.47
MAZ	10400	8400	9490	9620	10300	9642	10900	11100	10960	10650	10200	10762	10202	8.14
PUL	7420	8940	7680	8400		8110	9400	8670	9420	8720	8470	8936	8569	7.97
GNT	27694	28577	27274	29274	27274	28019	27373	28311	27229	32694	29577	29037	28527	5.95
GIN	11200	8400	9490	12590	11300	10596	12000		10900	11100	11400	11350	10931	11.59
COT	24894	28894	28894	25416	25416	26703	25416		31838	31838	31838	30233	28272	10.82
SCN	62721	61752	62760	63617	63617	62893	62550	57749	51759	56874	51443	56075	59484	8.01
TUR	57010	54142	62017	51877	48900	54789	49190		53928	41148	48560	48207	51864	11.42
TOB	18330	13356	19500		17867	17263	18900		19720	18718	19503	19210	18237	11.36
TAP	40014	40241	44100	43821	37560	41147	44604		48096	48092	48506	47325	43893	9.03
ONI	25776	24426	22446	25668	23850	24433	20466		22284	20502	21006	21065	22936	9.12
BAN	53997	49778	58993	60668	60668	56821	58993	59707	60668	59707	60668	59949	58385	6.21
SFL	13200		12400	13600		13067	14200			11400	12300	12633	12850	7.87
BRJ	24370	24370	23900	22590	24500	23946	21500	23600	21700	23200	21500	22300	23123	5.28
TOM	17600	16800	16200	15690	17400	16738	16500	15690	14620	13000	16500	15262	16000	8.54
CHI	23800	24900	22420	21300	22700	23024	24000	23000	22100	25420	21300	23164	23094	6.13
r_GN	6590	5175	5687	5144	5125	5544	5233	5061	5175	5687	5144	5260	5402	8.79
r_GI	4908	4740	4460	4600		4677	4678	4897	4960	3670	3987	4438	4544	9.75
r_CO	7830	6530	6520		5900	6695			6590	5860	4984	5811	6316	13.88
r_MZ	6700	5800	5060	5902		5866	5830	5740	5120	6200	6300	5838	5850	9.01
r_fC		3900	2800	3400		3367			3800	2750		3275	3330	16.23
r_CH	4200	3800	4280	4300		4145	4140	4300	4300	4800		4385	4265	6.43
r_PL	5621	5556	4956	6090	5402	5525	4981	5291	5417	5290	5920	5380	5452	6.66

Source: Estimated from farm sample

3.3 Productivity of major Crops under Homogenous Land Units

The productivity of major crops was estimated and the results would reveal that the average productivity of kharif paddy, rabi paddy, ragi and maize was 52, 40, 30 and 29 qtl/ha, respectively. The district average yield of these crops were 33.11, 29.06, 23.8 and 11.25 qtl per ha in Coimbatore district and 39.6, 41.65, 23.8 and 22.8 qtl per ha for Erode district, respectively. The average yield of sugarcane (as main crop) was 1080 qtl/ha. While, the district average productivity of sugarcane was 870 and 1020 qtl/ha in Coimbatore and Erode districts, respectively. The variation in crop productivity among the land units was however less as revealed from the coefficient of variation with exception of 37 per cent of CV for rainfed maize**.**

3.4 Net Income of Major Crops in Different Homogenous Land Unit Categories

The net income over the operational cost was estimated for the major crops in each of the HLUs and the result showed that turmeric recorded the maximum net income of INR 71848 per ha over operational cost, followed by banana (INR. 70827) and sugarcane (INR. 46767). The low water consuming crops yielded net returns as follows; cotton (INR. 13265), groundnut (INR. 44181), maize (INR. 10021) and onion (INR. 55762). In the ayacut land units (1CA, 1OA, 1RA, 1SA and ICG), the net return realized were comparatively higher at INR 16679 vs 11296 for kharif paddy, INR 8842 vs INR. 6899 for rabi paddy, INR 48433 vs 39928 for groundnut, 79050 vs 66086 for turmeric and INR. 58123 vs 35411 for sugarcane. The net income realized in each crop activity was considered in the land use model.

3.5 Current Cropping Pattern in Different HLUs

The alternative crop sets were optimize using the static land use model by using linear programming (LP) approach for each homogeneous land units with given land and water resource availability. In the land availability constraints 1.92 lakh ha was excluded which covers area under Tamarind, Guava, Mango, Coconut, Tea and Coffee. Similarly, the net ground water availability was estimated with the average pump output, well output in liter per second in each homogeneous land units for 52 standard weeks. The current cropping pattern revealed, after excluding area under perennial crops/trees, 17 major crops were cultivated in different HLUs of about 4.45 lakh ha in 2004-05. In order to understand the current status of the present cropping pattern, various efficiency indicators such as cropping intensity, cumulative land utilization index, share of the high and low water consuming crops, commercial crops, rainfed crops and area under vegetable crops were aggregated for each HLU and the results are presented in Table 4.

The analysis presented in Table 4 would show that paddy was cultivated in little over 58,000 ha followed by maize and sugarcane with 30281 ha and 25831 ha, respectively under irrigated condition. Groundnut, sorghum, pulses and fodder sorghum were the major rainfed crops that constituted 43-57 per cent of cropped area. Groundnut covered 47530 ha, next to sorghum with 91500 ha. The fodder sorghum occupied 52300 ha. The cropping intensity was relatively high in 1OA, 1CA followed by 1CG under ayacut land units (133, 120 and 119 per cent, respectively) whereas; it was 123, 128 and 105 under Non-Ayacut (0RG, 0CA, 0RA) land units. However cumulative land utilization index was relatively less in irrigated land units at 38 per cent compared to 46 per cent in Non-ayacut units. It would also be surprising to note that the area under high water consuming crops (paddy, banana, turmeric, tobacco and sugarcane) constituted almost 65 per cent of the area in non-ayacut land units but it was around 31 per cent in ayacut land units. This needed to be watched in terms of changes in the alternative crop set as we aim at a sustainable cropping pattern in this analysis. Rainfed crops normally dominated in non ayacut land units.

Table 4 Distribution of crops under current cropping pattern in ha*

	Non Ayacut area land unit						Ayacut area land units						
Crops	**0CA**	**0OA**	**0RA**	**0RG**	**0SA**	**All**	**1CA**	**1CG**	**1OA**	**1RA**	**1SA**	**All**	**WZ**
PADk	2076	3977	1504	181	553	8291	183		185	4004	424	4796	13087
PADr	12738	9142	8080	665	1242	31867	2655	468	1024	8685	290	13122	44989
RAG	15	18	84			117	5			70		75	191
MAZ	1757	2130	5589	44	146	9666	6553	4348	1005	7668	1042	20616	30281
PUL	236	785	351	37		1409	58		168	336	*139*	701	2110
GNT	899	2357	3679	189	348	7472	369	685	1345	5207	*1198*	8804	16276
GIN	2552	5107	1605	98	793	10155			183	2653	*1288*	4124	14280
COT	143	1454	1142	56	297	3092	4		249	1937	*1329*	3519	6610
SCN	4128	4763	7636	260	789	17576	715	1238	194	5733	*375*	8255	25831
TUR	2369	3664	1692	71	264	8060	114		128	1449	96	1787	9847
TOB	1564	206	794		454	3018			9	459	112	580	3599
TAP	280	1379	600		273	2532			44	825	287	1156	3687
ONI	306	1043	625	6	23	2003	433		119	621	38	1211	3212
BAN	3787	4413	1208	31	1212	10651	231	30	119	1054	151	1585	12236
SFL	170		580	37		787	45			1043	34	1122	1909
BRJ	75	389	132	7	1	604	16	55	22	127	54	274	878
TOM	237	1328	220	8	2	1795	85	119	607	352	114	1277	3072
CHI	254	447	331	18	73	1123	120	31	174	364	5	694	1817
r_GN	8408	8703	10861	800	3766	32538	6		3261	11607	118	14992	47530
r_GI	38	1826	705			2569	19	155	276	973		1423	3991
r_CO	618	7019	44			7681	213		1790	555		2558	10239
r_MZ	692	1267	3277	13		5249	160	398	1269	3088		4915	10164
r_FC	10484	13627	14068			38179			701	13422		14123	52302
r_CH	12043	40524	8289	206		61062	1955	2536	10831	15132		30454	91515
r_PL	4074	10724	1635	115	48	16596	4171	4589	6020	3937	85	18802	35398
GCA	**69940**	**126292**	**74731**	**2841**	**10284**	284088	**18110**	**14651**	**29723**	**91302**	**7179**	160965	**445051**
NSA	**54710**	**120288**	**71366**	**2311**	**24774**	273449	**15036**	**12280**	**22310**	**94147**	**14953**	158726	**432175**
CI	127.84	104.99	104.72	122.92	41.51	103.89	120.44	119.31	133.22	96.98	48.01	101.41	102.98
CLUI	59.08	44.44	47.81	55.98	21.79	45.82	44.02	42.20	45.85	40.99	21.27	38.87	44.06
LWC	25.27	39.06	43.88	29.31	37.26	34.956	66.35	75.10	70.42	50.87	80.84	68.72	45.34
HWC	74.73	60.94	56.12	70.69	62.74	65.044	33.65	24.90	29.58	49.13	19.16	31.28	54.66
COM	55.42	48.40	73.31	57.63	82.08	63.368	50.15	48.18	38.67	64.77	86.93	57.74	57.92
ir_Sh	48.02	33.73	47.97	60.10	62.91	50.546	63.98	47.60	18.76	46.65	97.18	54.83	43.57
r_Sh	51.98	66.27	52.03	39.90	37.09	49.454	36.02	52.40	81.24	53.35	2.82	45.17	56.43
veg_Sh	1.25	2.54	1.75	1.36	0.95	1.57	3.61	1.40	3.10	1.60	2.95	2.532	2.02

Irrigated crops: *PADk: Kharif paddy; PADr:Rabi Paddy; RAG:Rafi; MAZ:Maize; PUL:Pulses; GNT:Groundnut; GIN:Gingelly; COT:Cotton; SCN:Sugarcane; TUR:Turmeric; TOB:Tobaco; TAP:Tabioca; ONI:Onion; BAN:banana;SFL:Sunflower; BRJ:brinjal; TOM:Tomato; CHI:Chillies;*

Rainfed crops*: r_GN:groundnut; r_GI:gingelly; r_CO:Cotton; r_MZ:Maize; r_FC:fodder cholam; r_CH:cholam; r_PL:pulses*

***Efficiency indicators**: CI: Cropping intensity; CLUI: Cumulative land utilization index; LWC: Low water consuming crops; HWC: High water consuming crop (Paddy, Sugarcane, Turmeric, Tobaco and Banana)s; COM: Commercial crops; Ir_Sh: share of irrigated crops; r_Sh: Share of rainfed crops; veg_Sh: share of vegetables.*

(indicate what are HWC and LWC crops, also add 2 columns - total for non-ayacut and total for ayacut-also give %)

The analysis of HLU wise cropping pattern clearly revealed the fact that the current cropping pattern is ground water exploitative in nature, particularly in ground water deficit HLUs (0CA, 0OA, 1CA,1CG, 1OA), more specifically in the non-ayacut areas where the high water consuming crops dominated and alternately in the ayacut areas with higher cropping intensity ranging from 110 to 133 per cent. This warrants optimizing the current cropping plan for simultaneous increase in net income while reducing the pressure on ground water use.

3.6. Optimal (Alternative) Cropping Pattern

The alternative crops set was identified using the static land use model and the same presented in Table 5. The percentage change in area and income over the current plan for each crop activity was estimated and presented in Table 6.

Table 5. Optimal (Alternative) cropping pattern in Western zone in ha

	Non ayacut land units						Ayacut land units						
Crops	**0CA**	**0OA**	**0RA**	**0RG**	**0SA**	**All**	**1CA**	**1CG**	**1OA**	**1RA**	**1SA**	**All**	**WZ**
PADk	3039	6683	3965	128	1376	15191	835	682	1239	5230	831	8817	24010
PADr	2188	4812	2855	92	991	10938	601	491	892	3766	598	6348	17287
RAG	3647	8019	4758			16424	1002			6276		7278	23703
MAZ	3218	7076	4198	231	1304	16027	884	1228	2231	5538	1495	11376	27404
PUL	5471	12029	7137	122		24759	1504	646	1174	9415	787	13526	38284
GNT	2879	6331	3756	122	1077	14165	791	251	1174	4955	787	7958	22124
GIN	2879	6331	3756	100	506	13572			970	4955	650	6575	20148
COT	2379	5230	3103	47	563	11322	654		455	4093	305	5507	16829
SCN	1117	2455	1456	53	1304	6385	307	614	507	1921	340	3689	10073
TUR	1243	2734	1622	51	551	6201	342		1174	2140	787	4443	10644
TOB	2879	6331	3756		991	13957			496	4955	332	5783	19741
TAP	1216	2673	1586		476	5951			892	2092	598	3582	9534
ONI	2188	4812	2855	122	1304	11281	601		429	3766	288	5084	16364
BAN	1052	2313	1372	122	1239	6098	289		1174	1811	787	4061	10159
SFL	2879		3756	116		6751	791			4955	787	6533	13285
BRJ	2879	6014	3756	116	1304	14069	791		1116	4955	748	7610	21679
TOM	2735	6014	3568	122		12439	752		1174	4707	748	7381	19821
CHI	2735	6331	3568	128		12762	752		1239	4707	787	7485	20249
r_GN	2879	6683	3756			13318	791			4955	831	6577	19895
r_GI	3039		3965			7004	835			5230		6065	13070
r_CO	2735	6014	3568		1239	13556			1116	4707	748	6571	20127
r_MZ	2879	6331	3756	122		13088	791	646	1174	4955	787	8353	21442
r_FC		6331	3756			10087			1174	4955		6129	16216
r_CH	5471	6331	3756	231		15789			1174	4955		6129	21918
r_PL		12029	7137			19166			2231	9415		11646	30811
GCA	**63633**	**139905**	**90517**	**2024**	**14224**	**310303**	**13316**	**4559**	**23208**	**119412**	**14020**	**174515**	**484817**
NSA	**54710**	**120288**	**71366**	**2311**	**24774**	**273449**	**15036**	**12280**	**22310**	**94147**	**14953**	**158726**	**432175**
CI	116.31	116.31	126.84	87.57	57.41	113.5	88.56	37.12	104.02	126.84	93.76	109.9	115
CLUI	46.44	44.85	48.56	38.28	30.25	41.7	35.10	15.51	45.74	48.56	43.68	37.7	43.95

LWC	81.47	80.25	81.47	73.29	57.95	74.9	78.21	54.31	69.47	81.47	71.32	71.0	79.39
HWC	18.53	19.75	18.53	26.71	42.05	25.1	21.79	45.69	30.53	18.53	28.68	29.0	20.61
COM	68.86	64.33	67.29	71.66	83.36	71.1	70.39	60.08	71.08	67.29	84.20	70.6	65.95
ir_Sh	73.28	68.75	67.20	82.57	91.29	76.6	81.84	85.82	70.40	67.20	83.13	77.7	66.21
r_Sh	26.72	31.25	32.80	17.43	8.71	23.4	18.16	14.18	29.60	32.80	16.87	22.3	33.79
veg_Sh	16.56	16.56	15.19	24.07	18.33	18.1	21.75	0.00	17.06	15.19	18.33	14.5	13.30

CI: Cropping intensity; CLUI: Cumulative land utilization index; LWC: Low water consuming crops; HWC: High water consuming crops; COM: Commercial crops; Ir_Sh: share of irrigated crops; r_Sh: Share of rainfed crops; veg_Sh: share of vegetables.

Results presented in table 5 table 6 would show that the gross cropped area increased by nine per cent over current plan and generated the net income of INR 8.25 billion in the alternate plan compared to INR 6.14 billion under current plan. Area under low water consuming crops such as ragi, brinjal, irrigated pulses and chillies increased more than 10 times while area under high water consuming crops like; rabi season paddy, sugarcane and banana had reduced by more than 50 per cent over current plan. The increase in net income over current crop plan was by 34 per cent.

Table 6. Changes in alternative plan over current cropping pattern and in Western Zone

Crops	**Current cropping plan**				**Alternative crop plan**				**% increase over current plan**	
	Area		**income**		**Area**		**income**			
	ha	**%**	**L INR**	**%**	**ha**	**%**	**L INR**	**%**	**Area**	**income**
PADk	13087	2.94	164	2.67	24010	4.95	304	3.68	83.46	85.57
PADr	44989	10.11	506	8.25	17287	3.57	205	2.49	-61.58	-59.44
RAG	191	0.04	2	0.04	23703	4.89	274	3.32	12324	11050
MAZ	30281	6.80	378	6.15	27404	5.65	345	4.18	-9.50	-8.70
PUL	2110	0.47	42	0.68	38284	7.90	800	9.69	1714.32	1819.21
GNT	16276	3.66	699	11.39	22124	4.56	955	11.57	35.93	36.61
GIN	14280	3.21	305	4.97	20148	4.16	476	5.77	41.09	56.17
COT	6610	1.49	118	1.92	16829	3.47	291	3.53	154.60	146.97
SCN	25831	5.80	1158	18.86	10073	2.08	407	4.93	-61.00	-64.86
TUR	9847	2.21	482	7.85	10644	2.20	493	5.97	8.09	2.33
TOB	3599	0.81	23	0.38	19741	4.07	181	2.19	448.55	671.02
TAP	3687	0.83	37	0.61	9534	1.97	81	0.98	158.57	117.51
ONI	3212	0.72	79	1.29	16364	3.38	417	5.06	409.40	428.92
BAN	12236	2.75	604	9.84	10159	2.10	396	4.80	-16.97	-34.45
SFL	1909	0.43	37	0.60	13285	2.74	234	2.84	595.94	538.08
BRJ	878	0.20	25	0.41	21679	4.47	652	7.90	2369.14	2468.18
TOM	3072	0.69	70	1.15	19821	4.09	474	5.75	545.21	574.86
CHI	1817	0.41	0	0.00	20249	4.18	7	0.09	1014.40	3203.59
r_GN	47530	10.68	634	10.33	19895	4.10	297	3.60	-58.14	-53.10
r_GI	3991	0.90	37	0.61	13070	2.70	191	2.31	227.50	411.84
r_CO	10239	2.30	93	1.52	20127	4.15	225	2.73	96.57	141.37
r_MZ	10164	2.28	45	0.73	21442	4.42	100	1.22	110.96	122.94
r_FC	52302	11.75	58	0.94	16216	3.34	20	0.24	-68.99	-65.14
r_CH	91515	20.56	225	3.67	21918	4.52	47	0.57	-76.05	-79.27
r_PL	35398	7.95	317	5.16	30811	6.36	378	4.58	-12.96	19.37
GCA	**445051**	**100**	**6139**	**100**	**484817**	**100**	**8251**	**100.00**	**8.93**	**34.41**
NSA	**432175**				**432175**					

It could also be seen that the area under rabi season paddy decreased by about 62 per cent while a 83 per cent increase was noticed in kharif season paddy over current plan but overall, the total paddy area has reduced from 0.58 lakh ha to 0.42 lakh ha. The paddy area rather evened out between the kharif and rabi seasons. The decline was more pronounced in the non-ayacut HLUs, particularly in the greater ground water deficit ones. Among the other HWC crops, area under sugarcane and banana declined by 61.00 and 16.97 per cent respectively, while that of turmeric increased marginally by 8.09 per cent which may be due to higher net benefits. Among the low water consuming crops, there was a marginal reduction in area under maize by 9.50 per cent, whereas area under crops like, groundnut, gingelly, cotton and tapioca increased considerably ranging from 35.93 per cent to 154.60 per cent. In the case of ragi, tobacco, onion, sunflower and vegetables namely, brinjal, chilies and tomato, the increase was substantial ranging from 409.40 to 2369.14 per cent. Under rain fed conditions, area under groundnut, grain sorghum, fodder sorghum, and pulses declined in the range of 12.96 to 76.05 per cent, whereas, area under gingelly, cotton and maize increased between 96.57 and 110.96 per cent. The inference is shift from high water consuming and rain fed crops to low water consuming and commercial crops including vegetables. A comparison of table 3 and table 4 would also show that the cropping intensity declined in the critical, semi critical and over exploited HLUs, whereas it increased in the safe HLUs. The CLUI also shown a decline in the critical and over exploited HLUs in terms of ground water, while overall it showed a marginal increase. All these are sign of a crop set that will sustain resource base and simultaneously help to increase the farm income substantially.

4 Conclusion and policy implication

The static land use model was developed with an intension to identify an alternative cropping plan which would take care of the land and water resource use sustainability besides maximizing net income from crop enterprise in the Bavani basin of the western zone of Tamil Nadu in southern India. The land use model used the spatial variation in biophysical and socio-economic variables of a region by incorporating spatial attributes of land and water resources. The major biophysical factor considered are the land availability, ground and surface water availability, crop suitability for the particular soil type, crop sequence and climatic variations in terms of the length of growing period, and these factors were specified as the constraints in the land use model. The input data for the model were collected from the delineated HLUs. The optimum land use model reveals that there is possibility of increasing the crop income in the upper Bhavani basin of western zone of Tamil Nadu form current level of INR 6.14 billion to INR 8.25 billion. This alternative crop plan also helped to reduce the area under high water consuming crops in water deficit area without affecting the land and water resources base. Thus, it could be revealed from the land and water resource efficiency indicators for the alternative crop plan, resulted sustainable resource use with higher net income, achieved through the static bio-economic model.

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