Tradeoff between Non-farm Income and on-farm conservation investments in the Semi-Arid Tropics of India

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Abstract

This paper assesses the tradeoff between non-farm income and on-farm soil and water conservation investment by smallholder farmers in the semi-arid tropics of India using a dynamic bioeconomic model. This modeling approach allows understanding the complex interaction and feedback between household economic decision making and sustainability of natural resource base. A dynamic crop-livestock integrated bio-economic has been developed and calibrated for a Semi-Arid Tropics (SAT) watershed village in India where integrated watershed development program was implemented. The village level model is used to assess the impact of improved access to off-farm employment created by watershed development program on household welfare, land degradation and Soil and Water Conservation (SWC) labour used on-farm to reduce run-off and soil erosion. The simulation results revealed that improved non-farm employment opportunities in the village increases household welfare but reduces the households' incentive to use labour for conservation leading to higher levels of soil erosion and rapid land degradation in the watershed. This indicates that returns to labour are higher in non-farm than on-farm employment opportunities in the village. This appears to be no win-win benefits from improving the access to non-farm income in SAT rainfed farming villages. Complementary policies are required to protect the natural resource base.

Key words: Land degradation, Soil and Water conservation, non-farm income, Bioeconomic Model

1. Introduction

Land degradation due to soil erosion and decline in fertility status - in most of the developing countries - is becoming a major concern for agricultural development in changing socio-economic and environmental condition to meet future food needs of growing population and protecting the environment. In land-scare agrarian economies like India, the land degradation, especially in arid and semi-arid tropics (SAT) regions, is reaching irreversible levels like degraded uncultivable land and desertification (Reddy 2003). Sehgal and Abrol (1994) estimated about 190 million hectares as degraded land in India in about of the 297.3 million hectares of the total land. Almost two-thirds of the land is degraded in one form or other. The SAT region in India is characterized by high dependence on rainfall, water scarcity, frequent droughts, soil degradation and other biotic and abiotic constraints lower agricultural productivity and the resilience of the system (Shiferaw et al., 2003). The rainfed SAT regions of India account for two-thirds of the cultivable land and house a large share of the poor, food- insecure and vulnerable population of the country. Unless effective policy and technological measures are adopted to arrest the degradation, achieving sustainable development would remain a distant dream in rainfed SAT region of India.

In order to reduce land degradation in the rainfed, fragile SAT regions and to improve the crop productivity to secure food security, public and private soil and water conservation (SWC) investments on farm land is required. The incentives for private investments in SWC are often low due to long impact lags and the impact itself is not seldom impressive or dramatic (Kerr 2002). It is important to examine the incentive systems that encourage small farmers to undertake their own investment in SWC and feedback link in achieving sustainability of land and water resources.

Despite the policy relevance, empirical research on investigating the factors that influence farmers' decision on SWC and the positive and negative impacts on the sustainability of natural resource base is rather limited. This paper attempt to use integrated biophysical and socio-economic decision model to examine the economic benefits that farm households derive from their own SWC investments. And also to understand, how do non-farm income opportunities influence investments in private SWC?

The rest of the paper is organized as follows. Section 2 discuss about the Non-farm income opportunity and on-farm SWC investment. Section 3 provides basic data on the case study area. Section 4 presents the bio-economic model used for the simulations. Section 5 presents simulation results and discusses them. Section 6 presents the conclusion of the study.

2. Non-farm income opportunity and on-farm SWC investment

Empirical studies in semi-arid villages of India (Ramkumar et al., 2007; Sreedevi et al., 2004) have revealed that non-farm sources may account as much as 45–55% of average household income and seem to be growing in importance (Walker and Rayan, 1990).The rural household welfare, including food security is directly correlated with improved access to non-farm sources of income. But the impact of improved labour market access of the rural household on the management of natural resources is not clear.

The better access to non-farm income could lower the liquidity constraint faced by the farm households to purchase of farm inputs like seeds and fertilizers and result in intensive farming (Reardon et al., 1994). In contrast, if family labour is constraint, the improved access to labour markets could reduce on-farm labour use for agriculture. Due to higher opportunity cost in non-farm employment, the farm household decision between farm and non-farm activities is shown to be consistent with the objective of a household's welfare maximization and efficiency in the use of farm and household resources. Lee, Jr. (1965) model suggests that the availability of non-farm employment opportunities, coupled with the awareness of farmers of such opportunities, reduces labor allocation for on-farm activities. In this case farm households will not reduce the labour for activities with higher short-run benefits like sowing, weeding and harvesting but reduce the labour allocation for the activity with low short-run benefits like SWC. Shiferaw et al. (2003) found in their econometric study that in semi-arid villages in India the farmers reduce labour allocation for on-farm SWC with increase in non-farm income.

In this paper we hypothesize that non-farm employment opportunities will reduce family labor input in farm operations, especially for on-farm SWC in the SAT villages in India. This will occur because higher non-farm wage rate or opportunity cost makes on-farm activities less remunerative relative to non-farm activities. The farm households will respond by cultivating less land, mechanizing some tasks, or shifting to crops or techniques that are less management and labor-intensive. In wealthy countries, rising non-farm wages have historically been associated with mechanization and the adoption of less labor-intensive cropping patterns (Hayami and Ruttan 1985; Binswanger et al. 1978). In the SAT villages of India, rising non-farm wages may shift the family labour from relatively labor-intensive annual crops to less intensive farming systems, migrate to nearby towns to engage in non-farm activities.

To capture the impact of non-farm employment opportunities on sustainability of natural resources, we require a comprehensive treatment of biophysical as well as socio-economic conditions. So we developed a dynamic crop-livestock integrated bioeconomic model at village/watershed level. The advantage of bioeconomic models is that we can do with and without analysis with realistic specifications of market structures, the biophysical environment, and household preferences. They therefore represent a good tool for assessment of dynamic economy-environment linkages and policy effects (Barbier and Hazell, 2000; Okumu et al., 2002). We therefore assess how better access to non-farm income affects specifically on (a) household welfare, (b) agricultural production (output and input use), and (c) investment in land and water conservation.,.

3. The case study village: Kothapally, RangaReddy District, Andhra Pradesh, India

The Kothapally village lies between longitude 78 5’ to 78 8’ E and latitude 17 20’ to 17 24’ N in Ranga Reddy district. It is situated in Telangana region of Andhra Pradesh, nearly 50 km from Hyderabad, the capital city of the State. The Adharsa watershed of Kothapally village covers an area of 502.20 ha of which 465.75 ha land is cultivable and remaining land account for permanent fallow, wasteland, settlement and common property land. The area under irrigation in the watershed is only 20 per cent of the total cultivable land and the remaining land is under rainfed cultivation. The watershed is inhabited by 308 households where in 289 are farm households and 19 are landless labourers. The total population in the village is about 1624 inhabitants. The annual average rainfall in the area is about 800mm of which 85 per cent of it occurs between June to October (South west monsoon). The farmers grow crops in two seasons namely rainy season (*kharif*) from June to October and post rainy season (*rabi*) from November to February. The crops grown under rainfed condition in *rainy* season include sorghum, pigeon pea, maize, cotton, paddy, sunflower, and vegetable bean. The farmers cultivate paddy, vegetables, sunflower, chickpea and onion in post rainy season using residual moisture and supplement irrigation. Production of crops and livestock are well integrated in the watershed. Shiferaw *et al*. (2002) estimated more than two-third (72 per cent) of the sample households owned some livestock in addition to indulging in crop-production activities.

Household characteristics

In Kothapally, large farmers (greater than 4 ha) constitute about 10 per cent of the total households possess 38 per cent of the farmland with average landholdings of 6.84 ha (Table 1). Medium farmers (2 to 4 ha) are about 18 per cent of the total households hold 29 per cent of the farmland with an average landholding of 2.81 ha. On the contrary, small farmers (less than 2ha) who constitute 58 per cent of the households hold only 33 per cent of the farmland with an average landholding of 0.89 ha (Table 1). The average family size in Kothapally is 5.27 persons. The average weighted work force per household is 3.73 and average consumer unit per household is 4.57 persons, indicating the average consumer/worker ratio is 0.70.

Table 1 Land holdings of different household groups in Kothapally

Households	**No. of households**	**Total land area (ha)**	**Average land holding (ha)**
Small (<2ha)	202 (65.58)	159.67 (34.38)	0.72
Medium (2.01-4ha)	57 (18.51)	150.29 (32.16)	2.38
Large (>4.01)	30 (9.74)	155.79 (33.46)	4.71
Landless	19 (6.17)	0	0
Total	308 (100.00)	465.75 (100.00)	1.37

Note: Values in parentheses indicate the percentage to the total

The average income of the household groups by different income sources are given in Table 2. The non-farm income is the major source for the landless and small farmer groups. The small farmers groups earn non-farm income by working on other farmers' field as causal labour, non-farm income generation activities like petti shop, caste related occupation and migrate to nearby towns to work as casual labour in construction industry and running auto rickshaw etc. The medium and large farm groups earn more crop income than the non-farm income. The main source of non-farm income may be business, as salary and remittance etc.

Table 2 Average Income by source and household group in Kothapally village ('000 Rupees)

Household group	Crop Income	Non-farm Income	Livestock income	Total Income
Landless (n=3)	0.00	37.81	0.00	37.81
Small farmers (n=29)	6.92	14.85	3.45	25.22
Medium farmers (n=17)	17.56	11.59	3.58	32.73
large farmers (n=10)	42.83	31.40	10.56	84.79

Cattle and sheep are dominant types of livestock, but goat and backyard poultry are also common (Appendix 1). The small farmers are rearing more livestock when compared to the medium and large farmers, because of additional income they get through sale of livestock and milk. Bullock is the main source of traction power for ploughing and transportation. The farmers also rent bullock to other farmers for ploughing in peak season.

Biophysical characteristics

The Kothapally village is characterized by undulating topography (the slope of the land is about three per cent) and predominately black soils which range from shallow to medium deep black with a depth range from 30 to 90 cm. The watershed is classified into three types of soil depth namely shallow depth soil (less than 50cm), medium depth soil (50-90cm) and deep depth soil (greater than 90 cm). About 39 per cent of the total area in the watershed is shallow depth soil, 16 per cent is medium depth soil and 45 per cent of the area is deep depth soil. The detailed characterization of the soils shows that they are low in available N (11mg per kg of soil), available P (1.4 to 2.2 mg per kg of soil), Zinc (Zn), boron (B), and sulphur (S) in addition to low in organic carbon and mineral N content (Wani *et al*., 2003).

The farmers gain access to capital credit from formal and informal sources. The formal source of credit in Kothapally village is mainly the cooperative bank. The informal sources are moneylenders, friends, and relatives. In the village about 60 per cent of the sample farmers obtain credit from either formal or informal source. Of this some 70 per cent obtain credit from cooperative banks and the remaining 30 per cent from informal sources. The rate of interest is substantially lower in formal sector (9.4 per cent) than in the informal sector per year (14.8 per cent).

The labour market is active in Kothapally village around 70 per cent of the all farms employ hired labour during peak seasons. Wage labour is the primary source of income for 20 per cent of the households and is a secondary activity for 15 per cent of the households. Seasonal migration is only 5 per cent, probably because of demand for labour is high in the micro watershed.

Biophysical and Socioeconomic data

The village has an automatic weather station installed by ICRISAT[1], which allows regular monitoring of diverse biophysical parameters (e.g., temperature, rainfall, runoff, soil and nutrient loss etc.). The runoff, soil loss and nutrient loss from the treated and untreated segment of the watershed are measured using the automatic water level recorder and sediment samplers located at two different places in the watershed. The plot level data (e.g., soil depth, soil type, plot size, etc.) was collected through periodical visits and measuring some plots in the watershed and by interviewing the households owning or renting the plots. Based on information collected, the watershed area is divided into three soil depth classes based on top soil depth. The watershed is also further divided into two land types namely irrigated and rainfed or dryland based on the availability of irrigation facilities to the field. The summary of the data is presented in Table 3.

Based on the information from the census analysis a random sample of 60 households from Kothapally village and another 60 households from nearby villages were selected for detailed survey. A well-structured pre-tested questionnaire was used for data collection. The data was collected annually for three years (2002-2004). Along with other standard socioeconomic data, detailed plot and crop-wise input and output data were collected immediately after harvest from the operational holdings of all the sample households. The associated biophysical data on major plots (like soil depth, soil type, level of erosion, slope of the plot, fertility status etc.) were collected using locally accepted soil classification systems. The price data for the crops, livestock and market characteristics for crop produce, inputs and livestock were collected during the household survey, in the local markets and also through focus group discussion in the sample villages.

[1]ICRISAT implemented a participatory community watershed management programed in Kothapally village in collaboration with the Drought Prone Area Programme (DPAP) of Government of India. Along with ICRISAT, a consortium of NGOs and national research institutes is testing and developing technological, policy and institutional options for integrated watershed management in the village. A package of integrated genetic and natural resource management practices are being evaluated on farmer's fields (including SWC, new high yielding varieties, IPM and INM) through participatory approaches.

Table 3 Classification of land based on soil type and land type in Kothapally Village

Farmers	Soil type	Land type (ha)	
		Dryland	**Irrigated land**
Small (< 2.0 ha) (n=202)	Shallow	47.99	13.07
	Medium	22.28	5.36
	Deep	54.68	15.08
	Total	**124.95**	**33.50**
Medium (2.01 - 4.0 ha) (n=57)	Shallow	44.33	16.05
	Medium	19.54	6.59
	Deep	47.02	18.52
	Total	**110.89**	**41.16**
Large (> 4.01 ha) (n=30)	Shallow	40.73	18.80
	Medium	19.29	7.71
	Deep	46.32	21.69
	Total	**106.34**	**48.20**
All* (n=289)	Shallow	133.05	47.92
	Medium	61.11	19.66
	Deep	148.02	55.29
	Total	**342.18**	**122.86**

** Land less labour not included*

Note: n = number of farm households

4. Dynamic village level bioeconomic model

A dynamic non-linear bioeconomic model is developed for Kothapally village, where community participatory watershed project was implemented[2]. The model designed at the micro watershed level, includes three household groups (small, medium, and large framers), who are spatially disaggregated by six different segments in the watershed landscape

[2] The model is developed in the General Algebraic Modeling System (GAMS) (Brooke, Kendrick and Meeraux, 1992)

(defined by two land types and three soil depth classes). This gives 18 farm submodels within the watershed model.

The constraints are land, labour, capital, bullock labour, food, fodder for livestock, and soil depth. The main activities are crops, livestock production and on-farm and off-farm activities.

Endogenous variables are capitalized, coefficients are in small letters, and indices are subscripts.

Sets

a	livestock production activities
a1	milking animals (cows and she buffaloes)
a2	Bullocks
c	crop production activities
ct	conservation technology used to reduce soil erosion
cr	type of credit (formal and informal)
f	type of fertilizers (urea and DAP)
fl	fertilizer level used (fl = 1, 2,........,10)
h	three household groups (small, medium and large)
l	two land types depending upon irrigation (irrigated and rainfed)
n	dietary nutrients for human consumption (carbohydrates, protein and fat)
pn	plant nutrients in fertilizers (N and P)
r	discount rate
s	three soil depth classes (shallow, medium and deep)
sa	seasons (12 months of the year)
t	time in years
z	consumption of other purchased products (like meat, oil, egg, etc)

Variables

ASOILER	average soil erosion in each land unit in tons
BUYSED	amount of crop seed stocks purchased in tons
BUYCON	amount of crop product brought for household consumption in tons
BULHIRE	number of bullock days hired
CROP	crop production activities in ha
CROPYL	crop yield after erosion in tons per ha
CRESID	crop residual bought for animal feed in tons
CONS	on-farm consumption of crop product in tons
CONOWNA	on-farm consumption of young animals born or own animal slaughtering activities in heads

CONPURA	the amount of purchased animals consumed in heads
CONOP	the amount of other products consumed in tons (like meat, oil, egg, milk)
CREDIT	credit borrowed from different sources in Rupees
CUMSOILER	cumulative soil erosion in each land unit in each year in tons
CDEPTH	soil depth reduction from initial depth in cm
DEPTH	soil depth change due to erosion in cm
DMANURE	total manure (in tons) production per year
FERTBUY	fertilizers purchased in market in tons
FALLOW	fallow land in ha
FAMLAB	family labour in man-days
HINCOME	household group income in Rupees
HIRLAB	hired labour to work in the field in man-days
INCOME	income of the household group in Rupees
LABHIN	labour hired in from other households within the watershed in man-days
LABOFM	labour used in off-farm activities in man-days
LABNFM	labour work in non-farm activities in man-days
LIVPROD	livestock production activities in number
LIVBUY	livestock purchased in number during the year
LIVSAL	livestock sold in number during the year
LIVREAR	new born rearing activities in heads
MANUSE	amount of animal manure applied on the fields in tons
MPROD	milk production in litres
MILCONS	milk consumed in litres
MILSAL	milk sold in litres
MIG	permanent migration of population
NITRO	nitrogen applied to crops in tons
POP	population of the watershed village
PHOS	phosphorus applied to crops in tons
RENTIN	land rent in from other household group for cultivation in ha
RENTOUT	land rent out by household group to other group in ha
SEED	amount of own crop product used as seed stock in tons
SELCROP	amount of crop production sold in tons
STORED	crop product stored for next year in tons
STOREDC	crop product stored for consumption in next year in tons
STOREDS	crop product stored for sale in next year in tons
TINCW	total income of the watershed in Rupees
TPROD	total production of crops in tons
SOILER	amount of soil eroded in each land unit in tons
TSOILER	amount of soil eroded in whole watershed in tons
WFORCE	work force in the watershed

Coefficients

area (h,l,s)	available cultivable area of land (ha) for household group *h*, land type *l* and soil type *s*

amilkp (a1)	average milk production per milking animal *a1* per year
bprice (c)	the buying price of crop output *c* in Rupees per ton
bwage	wage rate for bullock hiring in Rupees
bullreq (l,s,fl,c,sa)	bullock days required for a ha of crop production *c*, in land type *l*, soil type *s*, fertilizer level *fl* and in season *sa*
bavail (a2, sa)	the number of bullock labour days available in season *sa*
brate	birth rate or calving rate of female animal
cprice (c)	the market price of crop output *c* in Rupees per ton
concost (a1)	average amount spent for buying concentrates for milking animals *a1* in a year
conslab (c,ct)	labour used for conservation of field for crop *c* grown with conservation technology *ct*
cost(c)	the cost of pesticides used for each crop *c* in Rupees per ha
cnut(n,c)	the composition of nutrient *n* (carbohydrate, protein and fat) in crop products *c* consumed
culrate	the culling rate for livestock
drymreq (a)	dry matter requirement for each livestock type *a* in tons per year
dm	dry matter content of the crop residual
erosion (c,ct)	soil loss in tons per ha of each crop *c* cultivated with conservation technology *ct*
erfact	erosion soil depth conversion factor (100 tons soil erosion per ha reduces 1cm of soil depth)
fprice (f)	the price of chemical fertilizers type *f* in Rupees per ton
fertlev (pn,fl)	level *fl* of plant nutrients *pn* applied in tons per ha
fnut (pn,f)	the composition of plant nutrients *pn* per ton of fertilizers *f* (urea and DAP)
fmig	fraction of population migrating
irate (cr)	interest rate in per cent for different credit type *cr* in per cent
labsup (h,sa)	labour supply per workforce in each household group *h* in season *sa*
labuse (h,l,s,fl,c,sa)	labour required (man-days) for ha of crop *c* cultivation by household group *h*, in land type *l*, soil class *s* using fertilizer level *fl*in season *sa*
livlab(h,sa)	labour required for livestock herd maintenance (man-days) for household group *h* in season *sa*
lprice (a)	the market price of livestock *a* in Rupees per head
livnut (n,a)	the composition of nutrients *n* (carbohydrate, protein and fat) in livestock *a* consumed
mprice	the price of milk in village market in Rupees per litre
mrate	the mortality rate for livestock
manpypa (a)	collectable dry manure produced by livestock *a* (in tons) per year per animal
manut (pn)	the composition of plant nutrients *pn* (N and P) per ton of manure (FYM) applied
nfwage	the non-farm wage rate in Rupees

nres (c,pn)	marginal effect of crop *c* yield for change in plant nutrients N in tons
nsqres (c)	marginal effect of crop *c* yield for change in plant nutrients N square (N^2)in tons
nutreq (h,n)	the total annual nutritional requirement of the household group *h* for nutrient *n*
opnut (n,z)	the composition of nutrients *n* (carbohydrate, protein and fat) in other products *z* consumed
oprice (z)	the price of other products *z* consumed in Rupees per ton
popg	growth rate of population
pres(c,pn)	marginal effect of crop *c* yield for change in plant nutrients P in tons
psqres(c)	marginal effect of crop *c* yield for change in plant nutrients P square(P^2)in tons
pliv	proportion of productive milking animals
rprice	the price of crop residual in Rupees per ton
rent (l,s)	price of rent in and out land by land type *l* and soil class *s* in Rupees per ha
sprice (c)	the price of crop *c* seed stock purchased in Rupees per ton
seedrate (c)	seed rate of crop *c* per hectare in tons
sdepth (h,l,s)	initial soil depth (cm) in each land units of household group *h*, land type *l* and soil class *s*
stoyld (c)	the stover yield for a ton of crop *c* grain yield in tons
vetcost (a)	average veterinary cost for each livestock *a* in a year
wage	the village market wage rate in Rupees
yield (l,s,c)	average yield of crop *c* in different land type *l* and soil class *s* in tons per ha
yred (s,c)	marginal effect of crop *c* yield for 1cm change in soil depth in tons in soil class *s*

Income functions

The model maximizes total income (*TINCW*) of the watershed defined as the present value of the sum of household groups' income (*INCOME*) over *T* periods.

$$TINCW = \sum_{h=1}^{H}\sum_{t=1}^{T}(1/1+r)^{t}\cdot\left(INCOME_{h,t}\right) \qquad (1)$$

The household group *h* net income (*INCOME*) in time *t* is sum of crop, livestock, non-farm and wage income less the costs incurred for farm production (like seed cost, fertilizers cost, labour cost), livestock rearing cost, feed cost and interest paid for the credit received from different sources. The income equation is as follows.

$$
\begin{aligned}
INCOME_{h,t} &= \sum_{c=1}^{C} TPROD_{h,c,t} \cdot cprice_c - \sum_{c=1}^{C} BUYSED_{h,c,t} \cdot sprice_c \\
&- \sum_{f=1}^{F} FERTBUY_{h,f,t} \cdot fprice_f - \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{c=1}^{C} CROP_{h,l,s,fl,c,t} \cdot cost_c \\
&+ \sum_{a=1}^{A} LIVSAL_{h,a,t} \cdot lprice_a - \sum_{a=1}^{A} LIVBUY_{h,a,t} \cdot lprice_a \\
&+ \sum_{sa=1}^{SA} LABOFM_{h,sa,t} \cdot wage + \sum_{sa=1}^{SA} LABNFM_{h,sa,t} \cdot nfwage - \sum_{sa=1}^{SA} HIRLAB_{h,sa,t} \cdot wage \\
&- \sum_{sa=1}^{SA} HIRBUL_{h,sa,t} \cdot bwage - CRESID_{h,t} \cdot rprice + MILKSAL_{h,t} \cdot mprice \\
&- \sum_{cr=1}^{CR} CREDIT_{h,ct,t} \cdot irate_{cr} - \sum_{a=1}^{A} LIVPROD_{h,a,t} \cdot vetcost_a - \sum_{a2=1}^{A2} LIVPROD_{h,a2,t} \cdot concost_{a2}
\end{aligned} \tag{2}
$$

Crop production

Crop production is a function of yield of crop *c*, in land type *l*, soil class *s*, at fertilizer level *fl*, conservation technology *ct*, at time period *t* and cultivated area of crop *c*, by household group *h*, in land type *l* and soil class *s*. The basic yield (*CROPYL*) of a crop *c* in household group *h*, land type *l*, soil class *s* at time period *t* can be increased by the application of inorganic fertilizers (N and P) and conversely yield would be decreased by change in soil depth (*CDEPTH*) of the cropland due to erosion. The quadratic yield function in the model is given as

$$
\begin{aligned}
CROPYL_{h,l,s,fl,ct,c,t} &= yield_{l,s,c} - yred_{s,c} \cdot CDEPTH_{h,l,s,t} + nres_c \cdot NITRO_{fl} \\
&+ nsqres_c \cdot NITRO_{fl}^2 + pres_c \cdot PHOS_{fl} + psqres_c \cdot PHOS_{fl}^2
\end{aligned} \tag{3}
$$

Total crop production (*TPROD*) of crop *c* by household group *h at* time period *t* is a function of endogenous crop yield (CROPYL) of crop *c*, in land type *l*, soil class *s*, at fertilizer level *fl*, conservation technology *ct*, at time period *t* and area (CROP) of crop *c*, in land type *l*, soil class *s*, at fertilizer level *fl*, conservation technology *ct*, at time period *t*.

$$
TPROD_{h,c,t} = \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\left(CROPYL_{h,l,s,fl,ct,c,t} \cdot CROP_{h,l,s,fl,ct,c,t}\right) \tag{4}
$$

The total crop production of crop *c* by household group *h* in year *t* is sold, stored, consumed by population and used as seeds. The household group *h* in year *t* is allowed to store the crop product for consumption and sell in the following year *t+1*. The crop production balance equation for crop *c* by household group *h* in year *t* is as follows

$$TPROD_{h,c,t} = CONS_{h,c,t} + SELCROP_{h,c,t} + SEED_{h,c,t} + STORED_{h,c,t} \quad (5)$$

$$STORED_{h,c,t} = STOREDC_{h,c,t+1} + STOREDS_{h,c,t+1} \quad (6)$$

Land use constraint

All the cultivable land in the village is divided into 18 homogenous land units. Each land unit is used for different combination of crops and the remaining land is left as fallow. The farmers in the village are allowed to rent in land for cultivation from other farmers. The land constrained equation in the model is

$$\sum_{c=1}^{C}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT} CROP_{h,l,s,fl,c,ct,t} + FALLOW_{h,l,s,t} + RENTOUT_{h,l,s,t} \leq area_{h,l,s} + RENTIN_{h,l,s,t} \quad (7)$$

The rented in (demand) land by land type *l*, and soil class *s* in year *t* must be less than or equal to rented out (supply) land by land type *l*, and soil class *s* in year *t*.

$$\sum_{h=1}^{H} RENTIN_{h,l,s,t} \leq \sum_{h=1}^{H} RENTOUT_{h,l,s,t} \quad (8)$$

Seed stock use

The seed rate per hectare of crop *c* is given exogenously. The total seed used by household group *h* in year *t* must be equal to sum of own seed stock (SEED) used by household group *h*, of crop *c* in year *t* and purchase seeds (BUYSED) by household group *h*, of crop *c* in year *t*.

$$seedrate_c \cdot \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT} CROP_{h,l,s.fl,ct,c,t} = SEED_{h,c,t} + BUYSED_{h,c,t} \qquad (9)$$

Fertilizer use

The macronutrients *pn*(N and P) required for crop *c* are applied through inorganic fertilizers (like urea and DAP) and farmyard manure (FYM). The nutrients applied to the fields by household group *h* in year *t* in the village must be equal to sum of inorganic fertilizers bought and FYM applied to the field by the household group *h* in year *t*. The equation is given by

$$\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{c=1}^{C}\sum_{ct=1}^{CT} CROP_{h,l,s,fl,ct,c,t} \cdot ferlev_{pn,fl} = \sum_{f=1}^{F}\left(fnut_{pn,f} \cdot FERTBUY_{h,f,t}\right) \\ + MANUSE_{h,t} \cdot 0.6 \cdot manut_{pn} + MANUSE_{h,t-1} \cdot 0.4 \cdot manut_{pn} \qquad (10)$$

Capital or credit constraint

The capital is constrained in the model, the expenses incurred by household group *h* in year *t* for crop *c* and livestock *a* production is met through cash income earned by the household group *h* at time period *t* through sale of crop *c*, livestock *a*, off income and non-farm income earned. The model is assumed to have access for formal and informal credit in the village. The capital and credit constraint equation of household group *h* in year *t* in the model is as follows.

$$\sum_{c=1}^{C} BUYSED_{h,c,t} \cdot sprice_c + \sum_{c=1}^{C} BUYCON_{h,c,t} \cdot bprice_c + \sum_{a=1}^{A} CONPURA_{h,a,t} \cdot lprice_a$$
$$\sum_{z=1}^{Z} CONOP_{h,z,t} \cdot oprice_z + CRESID_{h,t} \cdot rprice + \sum_{a=1}^{A} LIVBUY_{h,a,t} \cdot lprice_a$$
$$+ \sum_{cr=1}^{CR} \left(CREDIT_{h,cr,t-1} \cdot (1 + irate_{ct}) \right) + \sum_{sa=1}^{SA} HIRLAB_{h,ss,t} \cdot wage + \sum_{sa=1}^{SA} HIRBUL_{h,sa,t} \cdot bwage$$
$$+ \sum_{f=1}^{F} FERTBUY_{h,f,t} \cdot fprice_f + \sum_{l=1}^{L} \sum_{s=1}^{S} \sum_{fl=1}^{FL} \sum_{ct=1}^{CT} \sum_{c=1}^{C} CROP_{h,l,s,fl,ct,c,t} \cdot \cos t_c + \sum_{l=1}^{L} \sum_{s=1}^{S} RENTIN_{h,l,s,t} \cdot rent_{l,s}$$
$$+ \sum_{a=1}^{A} LIVPROD_{h,a,t} \cdot vet \cos t_a + \sum_{a2=1}^{A2} LIVPROD_{h,a2,t} \cdot con \cos t_{a2}$$
$$\leq \sum_{cr=1}^{CR} CREDIT_{h,cr,t} + \sum_{c=1}^{C} SELCROP_{h,c,t} \cdot cprice_c + \sum_{a=1}^{A} LIVSAL_{h,a,t} \cdot lprice_a +$$
$$+ \sum_{sa=1}^{SA} LABOFM_{h,sa,t} \cdot wage + \sum_{sa=1}^{SA} LABNFM_{h,sa,t} \cdot nfwage + + MILKSAL_{h,t} \cdot mprice$$
$$+ \sum_{l=1}^{L} \sum_{s=1}^{S} RENTOUT_{h,l,s,t} \cdot rent_{l,s} \qquad (11)$$

Food consumption

The subsistence food consumption needs of the population are defined in terms of minimum nutrient requirement (carbohydrates, protein and fat). The daily calorie requirement for a consumer is converted into nutrients and multiplied with total consumers in household group h in year t to arrive the total minimum nutrients required in tons. It is important to note in each year the population growth will affect the number of consumers in each household group and therefore the minimum food requirement also grows proportionally with population growth. The minimum nutrient requirement of the population is met by on-farm consumption of crop c output, purchased consumption crop c products, consumption of own animals a, consumption of purchased animals a and consumption of purchased product z (like meat, egg, oil, etc). The food consumption constraint equation for household group h in year t is given as

$$\sum_{c=1}^{C} CONS_{h,c,t} \cdot cnut_{n,c} + \sum_{c=1}^{C} BUYCON_c \cdot cnut_{n,c} + \sum_{a=1}^{A} CONOWNA_{h,a,t} \cdot livnut_{n,a}$$
$$+ \sum_{a=1}^{A} CONPURA_{h,a,t} \cdot livnut_{n,a} + \sum_{z=1}^{Z} CONOP_{h,z,t} \cdot opnut_{n,z} \geq nutreq_{h,n,t} \qquad (12)$$

Population and labour

The population in household group *h* at the end of year *t* is the beginning population (POP_{t-1}) adjusted for population growth rate (popg) minus permanent migrants (MIG). The permanent migration is limited to a fraction of the population. The population in household group *h* at time period *t* is converted into workforce (WFORCE) based on age and adjusted for growth rate of population.

$$(1+popg)\cdot POP_{h,t-1} - MIG_{h,t} = POP_{h,t} \tag{13}$$

$$MIG_{h,t} \le fmig\cdot POP_{h,t} \tag{14}$$

$$(1+popg)\cdot WFORCE_{h,t-1} - WMIG_{h,t} = WFORCE_{h,t} \tag{15}$$

$$WMIG_{h,t} \le fmig\cdot WFORCE_{h,t} \tag{16}$$

The labour days used by household group *h* for different farm activities (crop and livestock) in season *sa*at time period *t*, labour days used for conservation of land by household group *h* at time period *t*, labour days work on other household group farms (LABOFM) by household group *h* attime period *t*, and labour days work non-farm (LABNFM) by household group *h* at time period *t* have to be less than or equal to family labour (FAMLAB) in household group *h* in season *sa*at time period *t* plus the labour days hired in from other household group within the watershed (LABHIN) by household group *h* in season *sa*at time period *t*.

$$\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\sum_{c=1}^{C}\left(CROP_{h,l,s,fl,ct,c,t}\cdot labuse_{l,s,fl,c,sa}\right)+\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\sum_{c=1}^{C}\left(CROP_{h,l,s,fl,ct,c,t}\cdot conslab_{c,ct}\right)$$
$$+\,livlab_{h,sa,t} + LABOFM_{h,sa,t} + LABNFM_{h,sa,t} \le FAMLAB_{h,sa,t} + LABHIN_{h,sa,t} \tag{17}$$

The family labour plus off-farm and non-farm labour in household group *h* in season *sa* at time period *t* is less than the total work days available per household group *h* at time period *t*.

$$FAMLAB_{h,sa,t} + LABOFM_{h,sa,t} + LABNFM_{h,sa,t} \leq lab\sup_{h,sa} \cdot WFORCE_{h,t} \quad (18)$$

The following equation ensures the equilibrium of the supply of and demand for wage labour within the watershed in season *sa* at time period *t*.

$$\sum_{h=1}^{H} LABHIN_{h,sa,t} = \sum_{h=1}^{H} LABOFM_{h,sa,t} \quad (19)$$

Soil erosion and soil depth

The total annual soil loss in each land unit at time period *t* in the watershed is the result of cropping activities (CROP) for crop *c* by household group *h*, in land type *l*, soil class *s* at time period *t*. The following equation determines the soil loss in each land unit at time period *t*.

$$\sum_{fl=1}^{FL} \sum_{ct=1}^{CT} \sum_{c=1}^{C} \left(CROP_{h,l,s,fl,ct,c,t} \cdot erosion_{c,ct} \right) = SOILER_{h,l,s,t} \quad (20)$$

The total soil erosion in the watershed in year *t* is given by

$$\sum_{h=1}^{H} \sum_{l=1}^{L} \sum_{s=1}^{S} SOILER_{h,l,s,t} = TSOILER_{t} \quad (21)$$

The average soil erosion in each land unit at time period *t* is given by

$$ASOILER_{h,l,s,t} = \frac{SOILER_{h,l,s,t}}{area_{h,l,s}} \quad (22)$$

The cumulative soil erosion in each land unit in each year *t* is given by

$$CUMSOILER_{h,l,s,t} = ASOILER_{h,l,s,t-1} + ASOILER_{h,l,s,t} \quad (23)$$

The soil depth decrease as a result of soil erosion in each land unit in year *t* is given by

$$DEPTH_{h,l,s,t} = sdepth_{h,l,s} - erfact \cdot CUMSOILER_{h,l,s,t} \quad (24)$$

The change in soil depth from the initial soil depth of the land in year *t* is given by

$$CDEPTH_{h,l,s,t} = sdepth_{h,l,s} - DEPTH_{h,l,s,t} \tag{25}$$

Livestock modeling

The adult animalproduction by household group *h* in year *t+1* depends on initial animal in the start of the year *t*, animal bought, sold, young animal reared in the year, culling rate and mortality rate of the animal. The livestock type *a* production by household group *h* in a year *t* is estimated as follows.

$$\begin{aligned} LIVPROD_{h,a,t+1} &= (1 - culrate - mrate) \cdot LIVPROD_{h,a,t} + LIVBUY_{h,a,t+1} \\ &+ LIVREAR_{h,a,t} - LIVSAL_{h,a,t+1} \end{aligned} \tag{26}$$

Production of young animal type *a* by household group *h* in year *t* is computed based on the birth rate or calving rate of animal, consumption of young animal on-farm and selling of young animal in year *t*. The equation for young animal balance is given as

$$brate \cdot LIVPROD_{h,a,t} = LIVREAR_{h,a,t} + CONOWNA_{h,a,t} + LIVSAL_{h,a,t} \tag{27}$$

These equations are adjusted for different animal type *a* depending on the time required in different age classes and their reproduction characteristics.

Livestock feed requirement

The feed requirements for livestock type *a*in year *t* in the watershed have to be fulfilled by locally produced forage by crop *c* by household group *h*, in land type *l*, soil class *s*, at time period *t* or purchased crop residual by household group *h*, at time period *t*. The equation for livestock feed by household group *h*, at time period *t* is follows.

$$\begin{aligned} &\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\sum_{c=1}^{C}\left(CROP_{h,l,s,fl,c,t} \cdot CROPYL_{h,l,s,fl,c,t}\right) \cdot stoyld_c \\ &+ dm \cdot CRESID_{h,t} \geq \sum_{a=1}^{A} LIVPROD_{h,a,t} \cdot drymreq_a \end{aligned} \tag{28}$$

Milk production

The milk production in the watershed by household group *h*, at time period *t* is estimated by multiplying number of cow or she buffalo in household group *h*, at time period *t*, milk production per cow or she buffalo per year and the proportion of productive cows or she buffaloes. The milk produced by household group *h*, at time period *t* is either sold or consumed by the household groups.

$$amilkp_{a1} \cdot pliv \cdot LIVPROD_{h,a1,t} = MPROD_{h,a1,t} \tag{29}$$

$$MILCONS_{h,t} + MILSAL_{h,t} = \sum_{a1=1}^{A1} MPROD_{h,a1,t} \tag{30}$$

Bullock labour constraint

In the watershed farmers use bullock labour for land preparation, preparation of soil beds, transportation of produce from field to home and transportation of FYM to the fileds. In the model the demand for bullock labour days for household group *h*, at time period *t* must be satisfied by available bullock labour and through hiring of bullock by household group *h*, at time period *t* in the watershed.

$$\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\sum_{c=1}^{C}\left(CROP_{h,l,s,fl,c,t} \cdot bullreq_{l,s,fl,c,sa}\right) \leq bavail_{a2,sa} \cdot LIVPROD_{h,a2,t} + BULHIRE_{h,a2,sa,t} \tag{31}$$

Manure production

Organic manure (FYM) is used in the crop production to supply micronutrients along with inorganic fertilizers (urea and DAP). The manure production by household group *h*, at time period *t* is limited by number of livestock produced and reared and collectable manure production by each animal type *a* of household group *h*, at time period *t* in the watershed. The manure production by each household group in year *t* in the watershed is given as

$$DMANURE_{h,t} = \sum_{a=1}^{A}\left(LIVPROD_{h,a,t} \cdot manpypa_{a}\right) + \sum_{a=1}^{A}\left(LIVREAR_{h,a,t} \cdot manpypa_{a}\right) + \sum_{a=1}^{A}\left(LIVBUY_{h,a,t} \cdot manpypa_{a}\right) \quad (32)$$

The farmyard manure applied (MANUSE) in the fields by household group *h*, at time period *t* must be less than the manure production (DMANURE) by household group *h*, at time period *t*.

$$MANUSE_{h,t} \leq DMANURE_{h,t} \quad (33)$$

Soil nutrient balance

Nutrient depletion in the soils is one of the main causes for soil degradation. A soil nutrient balance in the watershed at time period *t* is the net removal (inflow minus depletion) of nutrients from the rootable soil layer. Nutrient balances are computed using the following equation (Okumu *et al*., 2002).

$$NUTBAL_{pn,t} = \left[\sum_{c=1}^{C}\left(TCAREA_{c,t} \cdot nutpha_{c,pn,t}\right) + \sum_{c=1}^{C}\left(TCAREA_{c,t} \cdot nitrofix_{c,pn}\right) + \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{h=1}^{H} area_{l,s,h} \cdot nutdep_{pn}\right]$$

$$- \left[\sum_{h=1}^{H}\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{c=1}^{C}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\left(CROPYL_{h,l,s,fl,ct,c,t} \cdot npkconh_{c,pn}\right) + \sum_{h=1}^{H}\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{c=1}^{C}\left(CROPRESY_{h,l,s,c,t} \cdot npkconr_{c,pn}\right) + TSOILER_{t} \cdot nleros_{pn}\right]$$

Where,

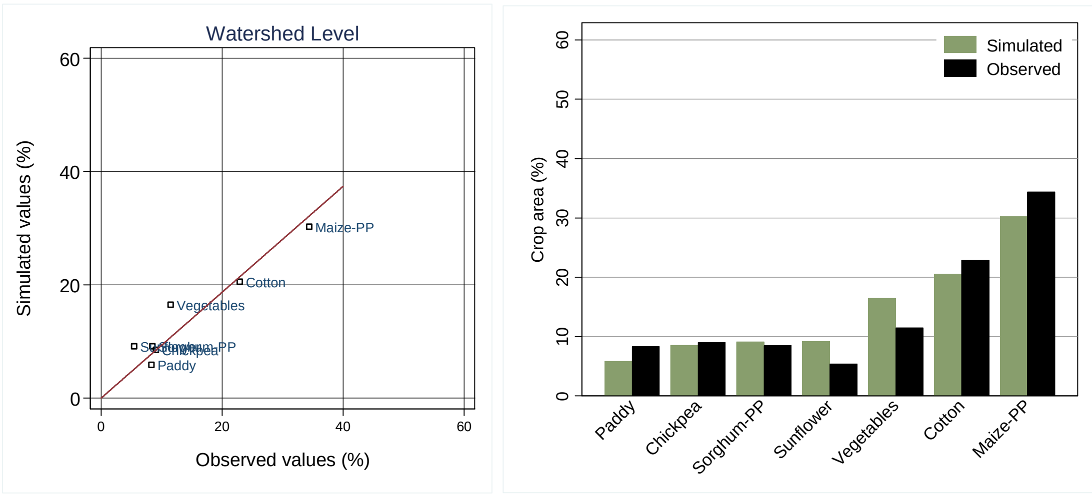
NUTBAL	nutrient balance of N and P in time *t*
TCAREA	total area of each crop *c* cultivated in the watershed in ha in time *t*
CROPYL	grain yield of each crop *c* in land type *l*, soil type *s*, fertilizer level *fl* and household group *h* in time *t*
CROPRESY	crop residual yield of each crop *c* in land type *l*, soil type *s*, and household group *h* in time *t*
TSOILER	total soil erosion in watershed in time *t*

nutpha (c,pn,t)	amount of nutrients *pn* applied on a unit (ha) of crop activity *c* through chemical fertilizers and FYM in time *t*
nitofix (c,pn)	amount of nutrient *pn*added to the soil by crop activity *c* e.g. nitrogen fixation.
nutdep (pn)	per ha addition of nutrient *pn*through atmospheric deposition
npkconh (c,pn)	amount of nutrient *pn* contained in a unit grain of crop *c* harvested
npkconr (c,pn)	amount of nutrient *pn* contained in a unit residual of crop *c*
nleros (pn)	amount of nutrient *pn* in a unit of soil lost through erosion

Validation of the Bio-economic model

The challenge in the development of the bio-economic models is to ensure that its results can be trusted and that the model can be re-used in the similar settings. The validation of the complex models like bio-economic models is much debated in the literatures (Janssen and Van Ittersum 2007). Based on McCarl and Apland (1986), the *ex-ante* bio-economic model was validated by conducting regression analysis between observed and simulated land use values. A regression line was fitted through the origin for the observed land use in 2003 and first year of simulated land use of major seven crops expressed in percentage to total area of these crops in the total cultivated area in the watershed. The comparison was done at watershed level. Figure 1 compares the observed with the simulated land use at the watershed level. The parameter coefficients are close to unity at watershed level with an explained variance of 97% (Figure 1) indicates the model results are almost identical with the 2003 land use trend in the Kothapally watershed.

Figure 1 Simulated vs Observed land use as % of total crop area (watershed level)



Regression line fit: Co-eff=0.93; SE=0.51; R2=0.97

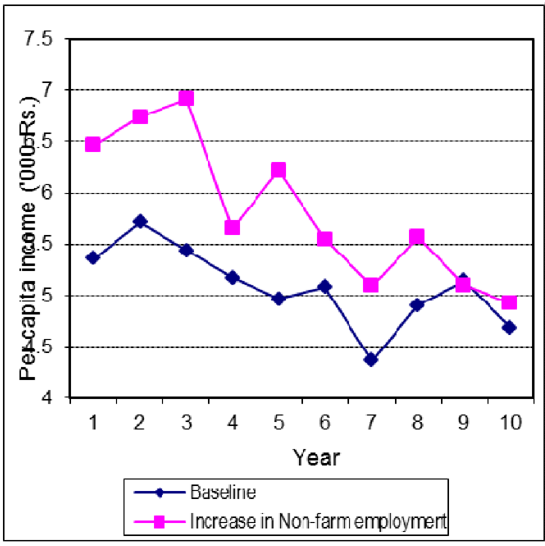
5. Scenario results: Increased access to non-farm opportunities in the village

The village level bioeconomic model is used to explore the impact of increased access to non-farm employment opportunities on household welfare, agricultural production, soil erosion, conservation incentives and nutrient mining in the watershed. Other than introducing soil and water conservation and productivity enhancement technology, watershed development programme in the village is also providing non-farm employment training (like vermi-compost production, NPV bio-pesticide production, tailoring etc.) and capacity building training to empowering rural women to improve the scope for enhancing their livelihoods of the households. In this context, it is assumed that the watershed programme is increasing the non-farm employment opportunities in the village.

The baseline scenario (where the non-farm employment is constrained) is compared with the alternative scenario of improved access to non-farm employment opportunities in the village. The results show that increase in non-farm employment leads to significant increase in per capita income of the three household groups. The per capita income for small and medium household groups is about 17 and 12 per cent above the baseline level (Figure 2 and 3). It is also found that the per capita income declines over the years for small and medium farmers as the income contribution from agriculture is lower because the farmers reduce the area under cultivation of crops to divert more labour to non-farm employment.

The average soil loss per ha in the watershed for increased non-farm employment opportunities and baseline scenario are given in Figure 5. The result shows that the soil loss per hectare is higher by six per cent compared to baseline level in the watershed. Figure 6 indicates that the decrease in rate of soil loss over the years is low when the non-farm employment is higher in the watershed. This shows the farmers lack incentives to use labour for SWC to reduce soil loss. This is because the opportunity cost of labour for non-farm employment is higher than the labour used of conservation measures. The Figure 7 reveals that when non-farm employment is more in the watershed the farmers use zero labour for conservation measures in the initial years of simulation because of diversion of the farm labour to non-farm employment which gives higher returns. However, the results show that increase in workforce due to population growth over years in the watershed allows the small and medium farmers to use their excess labour for conservation measures. When non-farm employment opportunity is increased in the watershed, the increase in soil erosion and nutrient loss was observed (Figure 8).

It is concluded that availability of better non-farm employment opportunities in the watershed does not result in win-win situation as the natural resource base will suffer more because of lack of incentive for natural resource management. These results are also consistent with findings of Shiferaw et al. (2003), where they found that the diversification into non-farm livelihood strategies could decline the level of fertilizer use, labour use and conservation investments per unit of land and hence land productivity (net returns per unit of land) is lowered for households who earn a significant portion of income from non-farm sources.



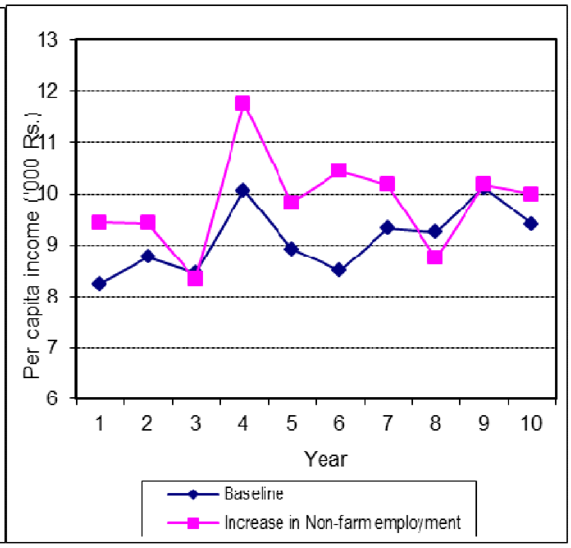


Figure 2 Per capita income for small farmers**Figure 3**Per capita income for medium farmers

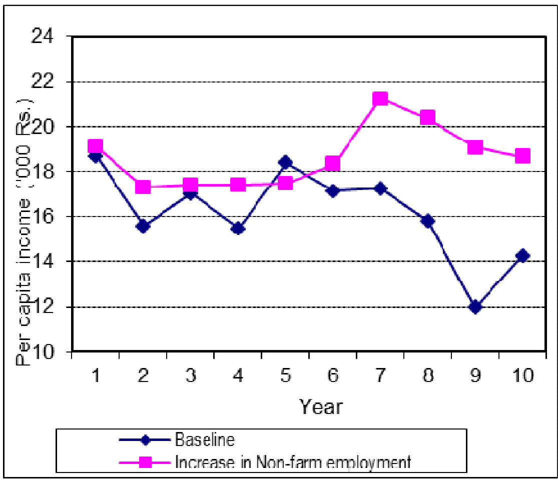
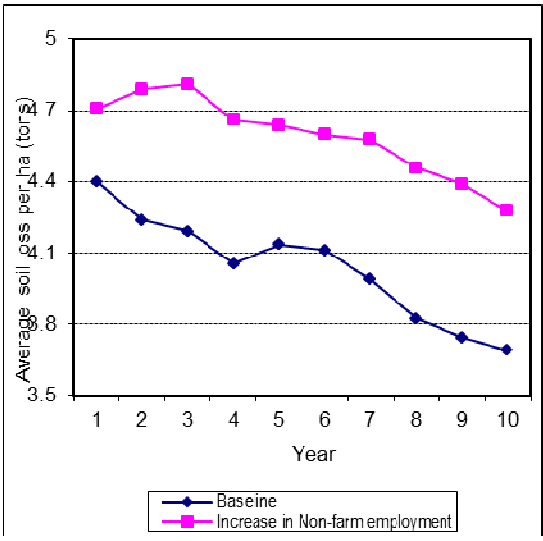


Figure 4 Per capita income for large farmers**Figure 5**Total soil erosion in the watershed:



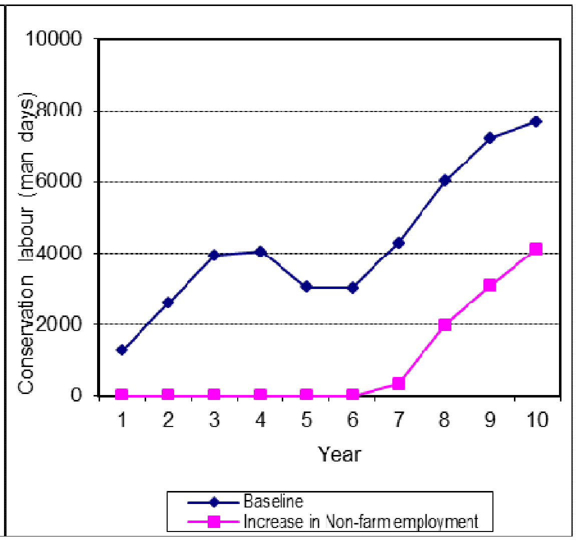


Figure 6 Average soil loss per ha**Figure 7**Total conservation labour used

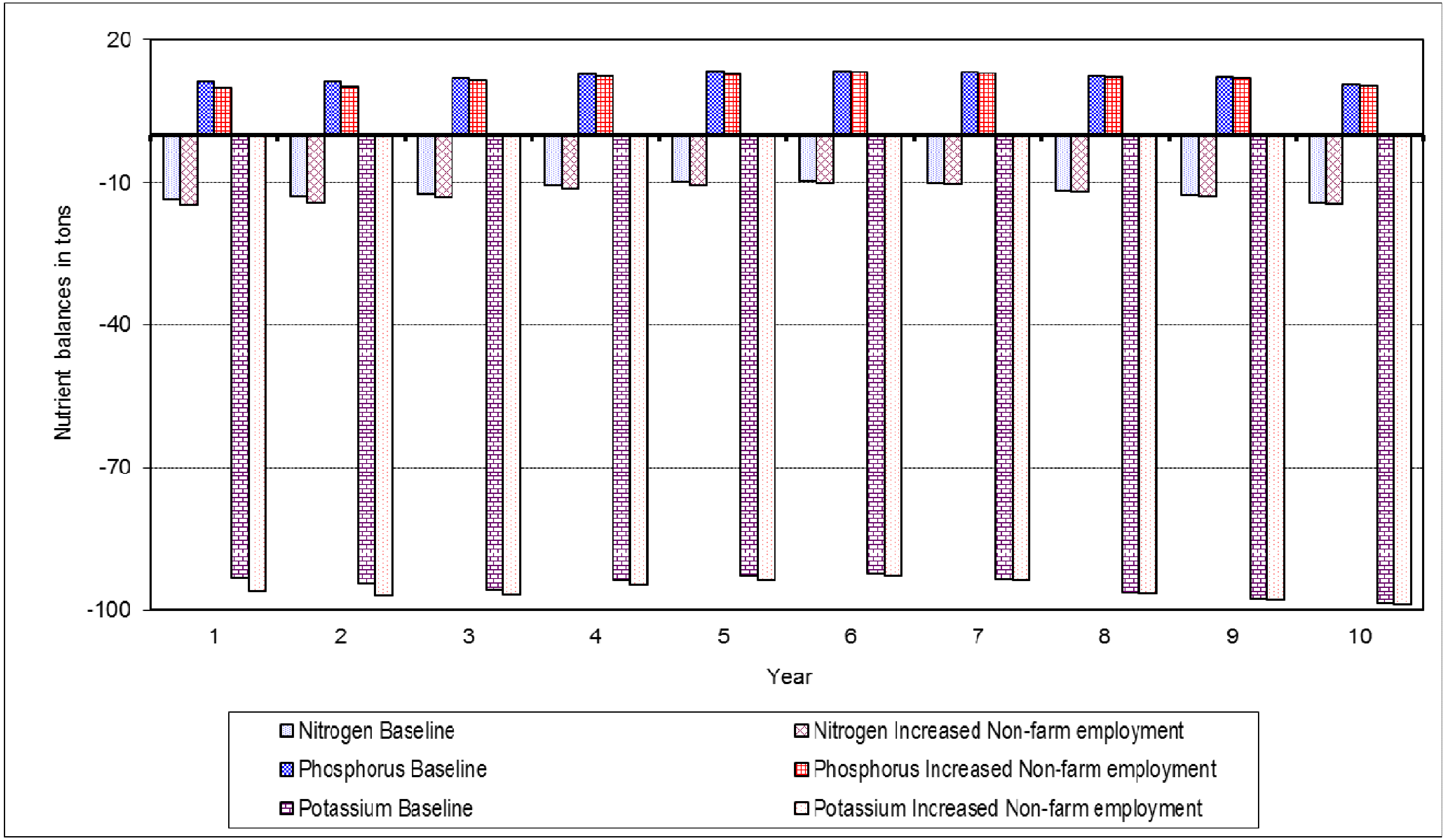


Figure 8 Simulated nutrient balances in the watershed

6. Conclusion and Recommendation

Land degradation in the form of soil erosion is a threat to the sustainability of natural resource and food security in the rainfed SAT regions of India. In this paper, we have developed and calibrated dynamic crop-livestock integrated bio-economic watershed level model to assess the impact of improved access to off-farm employment on household welfare, land degradation and conservation labour used in a SAT village in India. The simulation results revealed that improved non-farm employment opportunities in the village increases household welfare in terms of increase in household income but reduces the households' incentive to use labour for soil and water conservation leading to higher levels of soil erosion and rapid land degradation in the watershed. This indicates that returns to labour are higher in non-farm than on-farm employment. This simulation results indicate that there is no win-win benefits from improving the access to non-farm income in SAT rainfed farming villages through watershed program. In this case complementary policies are required to protect the natural resource base of the rainfed SAT regions.

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Appendix 1 Basic household and farm characteristics of different household groups in Kothapally (in 2001)

Particulars		Landless	Small	Medium	Large	Total
Number of households		19.00	202.00	57.00	30.00	308.00
Total population		89.00	993.00	356.00	186.00	1624.00
Average family size		4.68	4.92	6.25	6.20	5.27
Total work force		68.75	699.00	247.00	132.75	1147.50
Average work force		3.62	3.46	4.33	4.43	3.73
Total consumer units		77.75	860.05	308.85	159.70	1406.35
Average consumer units		4.09	4.26	5.42	5.32	4.57
Land holding information (in ha)						
Shallow land (< 50cm)	Irrigated	0	13.07	16.05	18.80	47.92
	Rainfed	0	47.99	44.33	40.73	133.05
Medium land (50-90cm)	Irrigated	0	5.36	6.59	7.71	19.66
	Rainfed	0	22.28	19.54	19.29	61.11
Deep land (> 90cm)	Irrigated	0	15.08	18.52	21.69	55.29
	Rainfed	0	54.68	47.02	46.32	148.02
Livestock information						
Bullocks		0	72	73	54	199
Cows		1	3	3	7	14
She Buffaloes		4	111	59	37	211
Sheep			147	125	20	292
Goat		2	69	16	9	96
Poultry		3	180	46	14	243