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ORIGINAL PAPER

Evaluation of cropping activities in the Adarsha watershed project, southern India

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Abstract Baseline data and data taken both during and after a watershed development program, recording cropping activities in a semi-arid watershed in Telangana, India, were analyzed. Watershed development contributed to the sustainable yield improvement of dryland crops by rehabilitating the productive capacity of the land through water and soil conservation techniques. On the basis of long-term data collected from farm households in the watershed, we explored ways to increase crop productivity and sustainability. Investment in soil and water conservation significantly impacted agricultural development, most particularly during droughts. Farmers realized returns to land amounting to US \$720 ha^{-1} from cotton, \$295 ha^{-1} from flowers, \$287 ha^{-1} from vegetables and \$171 ha^{-1} from cereals. Mean returns to labour, irrespective of crop strategies, was \$10 per person-day. Irrigation facilities in the watershed encouraged the growing of water-intensive crops but dryland crops were also more profitable as various in-situ and ex-situ interventions increased soil-moisture, providing congenial conditions for them. The responses were best during the watershed intervention period: yields of maize intercropped with pigeonpea were increased by 148 %, pigeonpea 100 %, sole sorghum 91 % and cotton 76.2 %. While droughts reduced the average share of household crop income in the non-watershed area from 44 to 12 %, this share remained unchanged at about 36 % in the watershed area. We deduce that watershed interventions have a positive influence on building resilient crop production.

Keywords Watershed programmes · Crop production · Sustanability · Semi-arid tropics

Introduction

Sustainable development and increased food production in agricultural based developing countries requires availability of sufficient water and fertile land. Water especially affects greatly the prosperity of people and their development potential and health. The availability of this vital resource is not guaranteed for large sections of the world's population. Over 40 % of the extra food required to meet the growing food demands by 2025 will have to come from intensified rainfed farming in Sub-Saharan Africa and South Asia (World Bank 2005, UNDP 2006). It is estimated that by 2025, India's population will reach 1.45 billion (United Nations, 2006) and the cereal requirement will be between 257 and 296 million tonnes, depending on income growth (Kumar 1998; Bhalla et al. 1999). Future food production must increase by about 5 million tonnes annually to ensure food and nutritional security for the burgeoning population (Kanwar 2000). Therefore, there is a recognized need to further examine the contextual factors associated with the development of new and environmentally sustainable agricultural technology (Ryan and Spencer 2001; Rosegrant et al. 2002; Molden 2007; Sahrawat et al. 2010; Wani et al. 2011, 2012). This requires a truly interdisciplinary approach to obtain and integrate the knowledge required (Fan et al. 2000; FAO 2006; Wani et al. 2006, 2008). In particular, in drought-prone areas, sustainable management of natural resources is a high priority for improving livelihoods and sustainability (Sharma et al. 2005; Wani et al. 2009).

Watershed development programmes have been initiated in India to improve and sustain productivity and the production potential of the drylands of the country through adoption of appropriate production and conservation techniques

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(Government of India 1994, 2002, 2007, 2008). Hydrologically, watersheds are typically catchment areas from where the water flows into a particular drainage system such as a river and may range in size from a few to several thousand hectares. Thus, according to the National Bank for Agriculture and Rural Development (NABARD 2006), watershed development refers to the "conservation, regeneration, and the judicious use of human and natural resources within a particular watershed through implementation of a 'ridge to valley' approach". In order to implement better activities and monitor them, larger watersheds are divided into several smaller ones, which overlap with administrative boundaries as much as possible. Development of small watersheds has been instrumental in raising agricultural productivity (Bouma and Scott 2006) and employment opportunities in the dryland regions of India (Kerr 1996; Joshi et al. 2008).

Since the 1970s, the Government of India has allocated substantial resources (US$7 billion) for improving dryland areas through watershed development programs (Joshi et al. 2005). Evidence from a cross section of Indian watersheds during recent years suggests that watershed development programmes have yielded significant economic and environmental benefits (Joshi et al. 2008). Given the focus of the federal government on using watershed programs as an important tool in accelerating development of dryland regions of the semi-arid tropics, it becomes imperative to assess the impact of these programs. This paper, using long-term household data, evaluates the performance of a semi-arid watershed with respect to cropping activities.

Data and methodology

Study area

The data used for this study was collected from the semi-arid Adarsha watershed of Kothapally in Telangana State, located

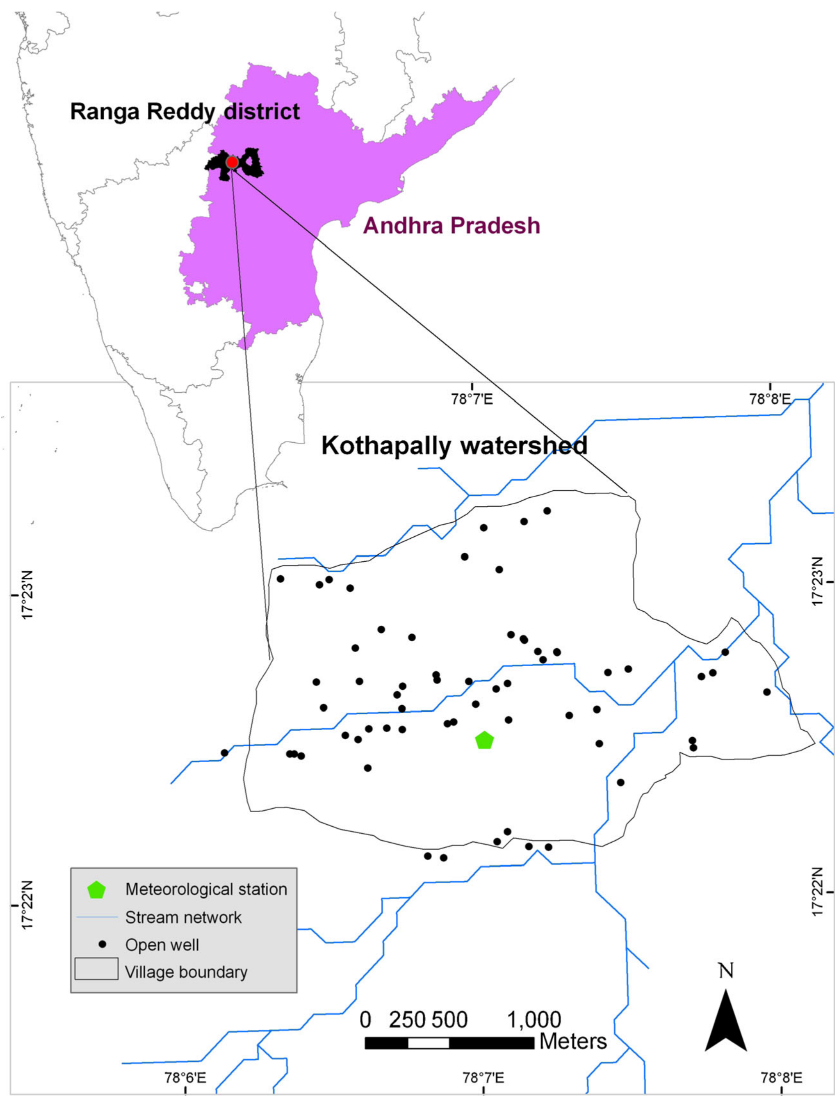


Fig. 1 Location map of Adarsha watershed, Kothapally, Telangana, (erstwhile Andhra Pradesh), India

between longitudes 78.27° East and latitudes 17.53° North and at an elevation of 500 m above mean sea level (Fig. 1). The watershed covers an area of about 465 ha and has medium to shallow black soils, with a depth of 30–90 cm and receives an average of 750 mm rainfall in the monsoon season (June to October). However, rainfall is highly erratic both in terms of intensity and distribution over time. Kothapally is a village of nearly 263 households, dependent largely on agriculture, either as owner-cultivators or landless labourers. About 70 % of the farmers are smallholders having less than 2 ha of land. Within the village boundaries, there are 62 open wells, most of which occur along the main watercourse but no deep tube wells. These open wells are limited in depth, ranging between 5 and 10 m. There were 15 borewells before the start of the watershed project, and 55 new borewells were dug during the project.

Watershed activities were undertaken in the village during the period 1999–2004, with help from the Government of Andhra Pradesh, Asian Development Bank and a consortium of partners including national, state and civil society organizations. Before the commencement of the project, agricultural activity in the watershed was limited to the rainy season and mono-cropping with low yield. The Adarsha watershed was selected mainly because more than 90 % of the cultivable area was rainfed and characterised by water scarcity; crop productivity was only 0.5–1.0 ton/ha; many open wells were defunct and the community experienced acute water shortage for drinking purposes, especially during the summer period; and the non-existence of water harvesting structures and the potential for minimum interventions to conserve soil and water.

A wide range of water and soil conservation techniques have been implemented since the inception of the watershed project, both at community and individual farm levels. The most common in situ interventions are contour and graded bunds in the fields. These minimize the velocity of runoff and allow more water to percolate into the soil, protecting it from erosion. Check dams on the streams and other ex situ practices reduce peak discharge and harvest a substantial amount of runoff, which increases groundwater recharge. At the same time, these dams trap sediments which protect the river ecosystems further downstream. The water in the check dams cannot be used directly for irrigation, the stored water being allowed to recharge groundwater aquifers by percolation. Instead, groundwater from open wells is used to irrigate crops (for more details see Garg et al. 2012; Garg and Wani 2012).

Data collection

Repeated household surveys were carried out in 1999, 2003 and 2010. These generated the data necessary to understand impact pathways and assess the effect of the integrated agricultural and resource management interventions on cropping activities in the watershed. The data included demographic details, socio-economic characteristics, information on crop enterprises and other related aspects.

Production costs and labour inputs for the selected crops and crop yields were extrapolated and reported as tons per hectare. Performance of crop activities was assessed at baseline, during the watershed intervention and post watershed intervention. The Adarsha watershed was implemented during the period 1999 to 2004. Therefore, the year 1999 was taken as the baseline scenario, 2003 as the watershed scenario and 2010 as the post watershed scenario. These scenarios allowed comparison of the major indicators of agricultural expansion such as area allocation, expansion of irrigated area due to watershed intervention, crop yield and production, resource use efficiency and crop choice.

Data analysis

The variables used to measure the performance of cropping activities in watershed areas included yield (kg ha^{-1}), returns to land (gross margin ha^{-1}), and returns to labour (gross margin person^{-1} day^{-1}). In order to compute revenues, gross yield was multiplied by harvest time price. In addition, resource use efficiency during different scenarios was estimated using the Cobb-Douglas production function after realizing that this method had shown econometric superiority over other methods. Gross margin was computed by subtracting current costs from gross revenues.

Computing crop categories and yield

Crops have been organized into five major groups based on their agronomic characteristics viz. cereals, vegetables, oilseeds, leguminous and others (cotton and flowers). For each crop group physical productivity was calculated. The physical productivity for a given crop enterprise refers to the total farm output per unit of land under a certain system. The total farm output included the amount marketed, consumed at home and that given out as social transfers. The physical output/productivity was calculated considering harvest time price for the product, multiplied by total quantity of produce and expressed in terms of economic returns (rupees. ha^{-1}).

The physical productivity of land is a function of land and water management along with other factors such as fertilizers, labour and machine power. Therefore, we considered physical productivity of land as a function of the overall efficiency of factors of production (Hatibu et al. 2006). In this paper, physical productivity was obtained by the following relationship:

$$P_{ij} = \frac{1}{n}\sum_{n}^{1}\frac{O_{ij}}{L_{ij}}$$

Where,

- P_{ij} = average productivity by i^{th} farmer for j^{th} crop enterprise (t ha^{-1});
- O_{ij} = output for i^{th} farmer from j^{th} crop enterprise (t);
- L_{ij} = acreage for i^{th} farmers for j^{th} crop enterprise (ha);
- n = number of farmers involved in j^{th} crop enterprises (i……n).

Returns to land and labour

In contemporary economic theory, returns to land and labour, are the major factors of production that receive higher priority over the other factors of production. We express returns to land and labour in terms of gross margin per hectare and per person day, respectively. Gross margin analysis is static and does not take into consideration the time value of money as compared to investment analysis. However, it is a useful tool that can assist in improving overall management as it addresses resource productivity in a given period of time (Hatibu et al. 2006). The basic equation for gross margin computation is presented as follows:

$$GM_{ij} = \frac{1}{n}\sum_{1}^{n} P_{ij}V_{ij} - VC_{ij}$$

Where,

- GM_{ij} = average gross margins earned by i^{th} farmer for j^{th} crop enterprise ($);
- P_{ij} = unit output price received by i^{th} farmer for j^{th} crop enterprise ($);
- V_{ij} = Volume marketed/values by i^{th} farmer for j^{th} crop enterprise (t);
- VC_{ij} = total variable costs (that vary with level of output) incurred by i^{th} farmer for j^{th} crop enterprise ($);
- n = number of farmers involved in j^{th} crop enterprise.

For returns to labour, the gross margins were expressed in person-days of family workforce employed in different farm operations.

Results and discussion

Area allocation for major crops

In the event of changing climate scenarios and fluctuations in market demand, diversification of crop pattern plays a crucial role. Crop diversification or area allocation to major crops, based on the above scenarios, is considered as a major risk aversion technique adopted by farmers. In the context of the watershed, farmers allocate area for different crops based on their yield potential as well as market demand. Evidence from the Adarsha watershed, suggests that dryland crops such as cereals have occupied greater area as soil moisture increased overtime due to watershed intervention. Table 1 reveals that the area under cereal crops has increased by more than one and a half times during the watershed intervention period compared to the baseline situation. Even after the watershed project had concluded, the increased area remained more or less the same. Similarly, leguminous crops also showed considerable progress during the watershed project period as the area under these crops increased from 8.2 ha at baseline to nearly 50 ha during the watershed period. Moreover, the area under cotton, a commercial crop, increased dramatically after the watershed intervention period. This can be attributed to increased demand for the crop, water availability for supplemental irrigation as well as a suitable agronomic environment. This led to it occupying more than 75 % of the land area available in the village (Garg et al. 2012). Thus, on the one hand, the area under food crops remained more or less static or declined over time and on the other, the area under commercial crops increased tremendously due to water availability and market demand (Table 1). Watershed interventions have changed farmers' mindsets towards crop diversification along with diversifying agriculture for economic gains.

Table 1 Area allocation for different crops in Kothapally, Andhra Pradesh (now Telangana), India (area in ha)

Crops	Baseline scenario (N = 54)			During watershed intervention (N = 60)			After watershed intervention (N = 60)		
	Kharif	Rabi	Total	Kharif	Rabi	Total	Kharif	Rabi	Total
Cereals	30.9	4.3	35.1	57.7	0.4	58.1	47.8	3.2	51.0
Vegetables & melon	5.0	0.9	5.9	5.0	1.8	6.9	5.7	6.2	12.0
Oilseeds	7.2	0.4	7.6	2.6	3.4	6.1	2.8	0.8	3.6
Leguminous	7.6	0.6	8.2	39.8	9.5	49.3	20.1	6.8	27.0
Others (cotton)	10.2	0.0	10.2	26.0	0.0	26.0	54.3	0.0	54.3
Others (flowers)	0.0	0.0	0.0	1.0	0.1	1.1	1.6	0.1	1.7
All crops (ha)	60.8	6.2	67.0	132.2	15.2	147.4	132.5	17.1	149.6

Source: Intensive household survey, 1999, 2003, and 2010

Cropping and irrigation intensity

The ultimate goal of watershed intervention is to increase water availability as well as soil fertility through the adoption of water and soil conservation techniques, along with nutrient management options. Access to irrigation depends upon its availability and infrastructure to facilitate its access. However, variability in rainfall and its low intensity may disturb water availability and irrigated agriculture. In Kothapally, the baseline scenario was better compared to the watershed scenario in terms of area under irrigation, largely due to severe drought during the year 2002, which affected water availability in 2003 due to poor groundwater recharge. Therefore, area under irrigation was slightly less that of the baseline situation. However, this increased considerably (>100 %) during the post-project scenario. Table 2 shows that cereals have a much greater area under irrigation compared to other crops. The baseline area under irrigation was 13.8 ha but there was a slight dip to 11.9 ha during the watershed intervention owing to the reasons mentioned above. However, post-project there was nearly 30 ha of cultivated land in the watershed area that was irrigated. This finding clearly revealed that the watershed intervention built resilience in terms of water availability.

Kothapally farmers had been using several improved cultivation practices such as Broad Bed and Furrow (BBF), soil-test based balanced fertilizer use, application of micronutrients and innovative pest and disease management. Improved seed varieties have also boosted agricultural productivity. During the watershed intervention in the village, a more than 11-fold increase in area (130.3 ha compared to the baseline of 11.8 ha) was brought under the cultivation of high yielding varieties (HYVs) but this dropped to 88.6 ha after the intervention (Table 3). The use of HYVs along with improved agricultural practices has brought significant yield benefits to the watershed.

Economics of crop production

Cost of cultivation

The cost of cultivation is the best testimony for assessing the economics of crop production. Table 4 shows that watershed development in Kothapally has brought changes in terms of social awareness, economic benefits and environmental management. During the baseline scenario, farmers in Kothapally were not much aware of the positive impacts of improved seeds, seed treatment and fertilizer management. As shown in Table 4, there was little investment in seeds and seed treatment. Before the watershed intervention the farmers used seeds they had prepared themselves using traditional knowledge of storage and treatment of seeds. During the watershed project there was a sharp rise in expenditure on seeds and seed treatment for vegetables and cotton and this continued after the project had ended. Similarly, before the watershed intervention, soil fertility management was addressed through application of large quantities of nitrogenous fertilizers in order to enhance yields without realizing its negative consequences. However, after the watershed intervention, attention was given to soil fertility management by following balanced fertilizer applications. It is worthwhile noting that the watershed intervention encouraged collective action in the community and, as a result, women have started vermicomposting as an income-generating activity in the village.

Yield variation

Through field trials undertaken by farmers, the watershed program intervention identified the best options to increase productivity. Better nutrition along with improved cultivars, integrated pest management (IPM) and land and water management practices increased yields from various

Table 2 Irrigated area under different crop categories (ha)

Crops	Baseline scenario			During watershed intervention			After watershed intervention		
	Kharif	Rabi	Total	Kharif	Rabi	Total	Kharif	Rabi	Total
Cereals	7.0	4.3	11.3	4.9	0.4	5.2	15.5	2.8	18.3
Vegetables & melon	0.8	0.9	1.7	2.6	1.8	4.4	2.0	4.4	6.4
Oilseeds	0.1	0.0	0.1	0.0	0.8	0.8	0.0	0.0	0.0
Leguminous	0.1	0.6	0.7	0.0	0.2	0.2	0.6	0.0	0.6
Others (cotton)	0.0	0.0	0.0	0.4	0.0	0.4	2.4	0.0	2.4
Others (flowers)	0.0	0.0	0.0	0.8	0.1	0.9	0.3	0.1	0.4
All crops (ha)	8.0	5.8	13.8	8.7	3.3	11.9	20.9	7.3	28.2

Source: Intensive household survey, 1999, 2003, and 2010

Table 3 Area under improved variety seeds (ha)

Crops	Baseline scenario	During watershed intervention	After watershed intervention
Cereals	1.3	49.9	23.8
Vegetables & melons	0.4	4.4	7.2
Oil seeds	0.3	4.9	2.8
Leguminous crops	0.0	44	19.7
Cotton	9.8	26	35
Flowers	0.0	1.1	0.1
All crops (ha)	11.8	130.3	88.6
Percentage share to total cultivated area	17.6	88.4	59.2

Source: Intensive household survey, 1999, 2003, and 2010

crops (Table 5). The yields of major crops given in Table 5 show that the watershed intervention had marked positive effects on crop production throughout the decade, yields increasing by 148 % (maize intercropped with pigeonpea), 100 % (pigeonpea), 91 % (sole sorghum) and 76.2 % (cotton; Table 5). Moreover, with the improved water availability and land management practices, the conventional cropping system has become more diversified with farmers making use of the available soil moisture to introduce chickpea during the rabi season.

Resource use efficiency

Farmers aim at allocating the available scarce resources in the most efficient manner. The watershed intervention fostered a sense of ownership and collective responsibility among the farming community to achieve this. For example, in Kothapally, there is no provision for obtaining water from water harvesting structures, which are strictly meant for the purpose of groundwater recharge. Since open wells and tube wells are major sources of irrigation, the community took a

Table 4 Cost of crop-cultivation (**\$ ha^{-1}**)

Crops	Area (ha)	Human and bullock services	Seeds and seed treatment	Soil fertility management
Baseline scenario				
Cereals	35.1	4.8	2.0	31.8
Vegetables	5.9	3.8	7.6	76.6
Oilseeds	7.6	2.7	3.3	46.1
Leguminous	8.2	2.6	8.4	40.4
Cotton	10.2	9.2	9.7	114.3
Watershed scenario				
Cereals	58.1	28.7	5.3	37.2
Vegetables	6.9	57.1	25.5	51.0
Oilseeds	6.1	21.3	6.7	19.3
Leguminous	49.3	9.8	5.7	16.0
Cotton	26.0	35.6	27.1	95.5
Flowers	1.1	30.9	3.7	33.8
Post project scenario				
Cereals	51.0	74.0	17.7	72.1
Vegetables	12.0	91.3	37.2	81.7
Oilseeds	3.6	47.5	5.5	24.8
Leguminous	27.0	45.1	17.3	43.5
Cotton	54.3	95.0	35.5	102.9
Flowers	1.7	49.9	0.0	91.0

Source: Intensive household survey, 1999, 2003, and 2010

Table 5 Yield variation of major crops during different phase of watershed intervention in Kothapally

Crops	Average yield (Kg ha^{-1})		
	Baseline scenario	During watershed intervention	After watershed intervention
Cotton	1050	1850 (76.2)	1300 (23.8)
Sole maize	1500	2350 (56.7)	2020 (34.7)
Maize intercrop with pigeon pea	1000	2480 (148.0)	2220 (122.0)
Paddy	2190	2500 (14.2)	2230 (1.8)
Sole sorghum	440	840 (90.9)	980 (122.7)
Sorghum intercrop with pigeon pea	-	450	510
Pigeon pea	490	980(100.0)	1000 (104.1)
Chickpea	-	500	340

Source: Intensive household survey, 1999, 2003, and 2010

Figures in brackets are yield improvement (%) over baseline scenario

decision to restore groundwater by conserving surface water to recharge wells. The community rule (informal norms) was introduced during the year 2000 at the behest of the watershed committee after consultation with different stakeholders. The ban on obtaining water from water harvesting structures was prompted by the importance of irrigation water during the off-season. Considering these kinds of collective initiatives to manage resources, an attempt has been made here to explore how resource use efficiency differed between different watershed management scenarios in Kothapally. Considering the different functional forms such as linear, Cobb-Douglas, quadratic and transcendental, the Cobb-Douglas model offered econometrically meaningful results. The estimated function is:

$$LogY = \log a + b_1 \log X_1 + b_2 \log X_2 + b_3 \log X_3 + b_4 \log X_4$$

Where,

- Y = annual gross return per farm (Rs);
- X_1 = area (ha);
- X_2 = value of human and bullock services;
- X_3 = value of seeds and seed treatment and
- X_4 = value of soil fertility management activities.

The function was estimated separately for different scenarios viz. the baseline scenario, the watershed scenario and the post project scenario. Since the production function is for the whole farm, we used gross returns from all crops in the watershed. Explanatory variables contributing to multicollinearity were deleted.

The Cobb-Douglas production function, estimated separately for the three different scenarios, are reported in Table 6. The elasticity of gross return for volume of seeds used was 0.14 during the baseline scenario and 0.16 for the watershed intervention scenario. Also, the elasticity of gross return for volume of fertilizer used was 0.33 during the baseline scenario and 0.62 during the watershed intervention phase but not significant during the post-project scenario. This

Table 6 Resource use efficiency in Adarsha watershed, Kothapally, Andhra Pradesh, India

Particulars	Baseline scenario	Watershed scenario	Post project scenario
Constant	2.571	1.942	2.351
Area	0.296**	0.308*	0.336***
	(2.522)	(2.997)	(1.868)
Value of human and bullock services	0.000396	-0.102	0.438**
	(0.070)	(−0.887)	(2.183)
Value of seeds and seed treatment	0.147***	0.164***	0.0086
	(1.699)	(1.821)	(0.822)
Value of soil fertility management activities	0.328	0.623*	0.0039
	(1.470)	(4.873)	(0.165)
R2	0.39	0.69	0.33
N	54	55	60

*,**,*** significant at the 10, 5, and 1 % level, respectively. Figures in parentheses are ‘t’ values

clearly shows that resources were being used effectively during the watershed intervention phase compared with pre-project and post-project phases. Moreover, farmers realized that the elasticity was higher during the watershed intervention phase when compared to the baseline situation.

Factors determining choice of dryland crops

The aim of watershed development was to increase groundwater levels in order to provide drought proofing (Garg and Wani 2012; Oweis et al. 1999) and allow opportunities for farmers to cultivate water-intensive high value crops. However, the decision of what crops to cultivate depends on many other factors as well. Supplemental irrigation plays a major role in sustaining dryland crops, especially when rainfall is scanty. In Kothapally, about 40 % of the cultivated area is under supplemental irrigation during some part of the year (Garg et al. 2012). From an economic perspective, this makes sense as it increases the profitability of dryland crops, but from a hydrological perspective it may put pressure on the aquifer system. However, supplemental irrigation is a reality in watershed areas in general and Kothapally in particular.

In an effort to examine households' choices of dryland crops in watershed areas, we assessed whether farmers with access to groundwater irrigation indeed tend to shift to more water intensive crops. To examine this aspect, we estimated the probability of a household growing dryland crops on a plot with access to irrigation using 'probit analysis'. This determines the probability that a household with irrigation grows a dryland crop (=1) or not (0 = otherwise). We have estimated the probability for watershed and post-watershed intervention scenarios.

Farmers with access to irrigation (represented by the amount of irrigated area) do not opt for dryland crops. This becomes apparent from the significant negative effect irrigation has on the choice of dryland crops. Second, soil depth, soil slope along with distance from residence play major roles in deciding whether to opt for dryland crops as these are the deciding factors for crop cultivation where favorable environment exists for diversification. Third, the toposequence, both during watershed and post watershed intervention, seems to have been a deciding factor for choice of dryland crops in watershed areas. However, the plots near the check-dams and wells seem to have positive effects on choice of dryland crops as they facilitate increasing moisture content in the soil. It is needless to mention that the larger the plot size the greater the probability of allocating land for dryland crops (Table 7). Hence, it is obvious that watershed management has influenced cultivation of dryland crops, at the same time it has also resulted in crop diversification with supplementary irrigation.

Relationship between water harvesting structures and crop diversification

Rainwater harvesting structures are an integral part of the watershed development program since they help recharge the groundwater aquifers (Wani et al. 2002, 2003; Batchelor et al. 2003; Garg et al. 2012). Harvesting rainwater for this purpose can help to sustain greater water intensive agricultural production, but it is likely also to reduce the flow of surface water to users downstream. When users near the check-dams have access to the recharged aquifers there are possibilities of adopting water intensive high-value crops. It is important to

Table 7 Factors determining the choice of dryland crops

Particulars	Watershed period		Post project period	
	Probit estimate	Marginal effects	Probit estimate	Marginal effects
Constant	0.42 (0.64)		1.23 (2.97)	
Toposequence (dummy)	0.74 (2.46)**	0.20	0.55 (2.03)**	0.18
Soil depth (dummy)	-0.86 (−1.94)***	-0.19	-1.31 (−4.20)*	-0.40
Soil slope (dummy)	-0.75 (−2.17)**	-0.20	-0.56 (−2.10)**	-0.09
Soil fertility (dummy)	0.68 (1.27)	0.23	-1.14 (−4.03)*	-0.36
Distance from residence (km)	-0.54 (−0.24)	-0.01	-0.02 (−0.33)	-0.008
Distance from check dam (km)	0.22 (0.30)	0.06	0.66 (1.23)	0.13
Distance from well (km)	0.23 (1.09)	0.06	1.48 (2.12)**	0.53
Plot size (ha)	1.98 (3.28)*	0.57	1.81 (3.47)*	0.64
Amount of irrigated area (ha)	-12.57 (−3.44)*	-3.60	-2.94 (−4.16)*	-1.04
No. of observations	198		193	
Log likelihood	-55.66		-67.90	
Pseudo R^2	0.48		0.49	
LR chi^2 (df)	103.33		127.96	

*,**,*** significant at the 10, 5, and 1 % level, respectively. Figures in parentheses are 't' values

note that check dams can have several impacts other than changes in water availability. Increase in soil moisture can help to improve the productivity of rainfed agriculture and also help in controlling soil erosion as well.

Improved groundwater availability in the watershed village encouraged crop diversification with increased economic gains (Fig. 3). Analysis with respect to distance from check dams reconfirmed the fact that increased water availability encourages cultivation of high-value crops such as vegetables for profit (Sreedevi et al. 2004, Wani et al. 2007). Figure 2 reveals that the area under high-value crops is on an increasing trend compared to the baseline situation. The yield of high-value crops cultivated near the check-dams (<250 m) increased to 6780 kg ha^{-1} for vegetables and 1870 kg ha^{-1} for cotton during the watershed scenario. The same trend continued even after the end of the project where high-value crops such as vegetables and cotton registered higher yields and income compared to other dryland crops. Dryland crops cultivated near the check dams have performed well in terms of yield. For example, during the watershed scenario the pigeonpea-maize intercrop yield was 1540 kg ha^{-1} and sole maize yield was 2720 kg ha^{-1}.

The watershed interventions, which improved substantially the green water resources, apparently led to better utilization of available water resources in productive transpiration and resulted in more food per drop of water. Thus, integrated soil, crop and water management with the objective of increasing the proportion of the water balance as productive transpiration, which constitutes one of the most important rainwater management strategies to improve yields and water productivity, is effectively addressed through participatory watershed interventions (Fig. 3).

Economics of crop production

After determining the factors that influence choice of dryland crops in watershed areas, we now turn our discussion towards returns to factors of production in agriculture. After taking into account prices and costs of production, the yields of different crops realized during the watershed and post-watershed intervention period are expressed in financial returns to land and labour with respect to different crop categories.

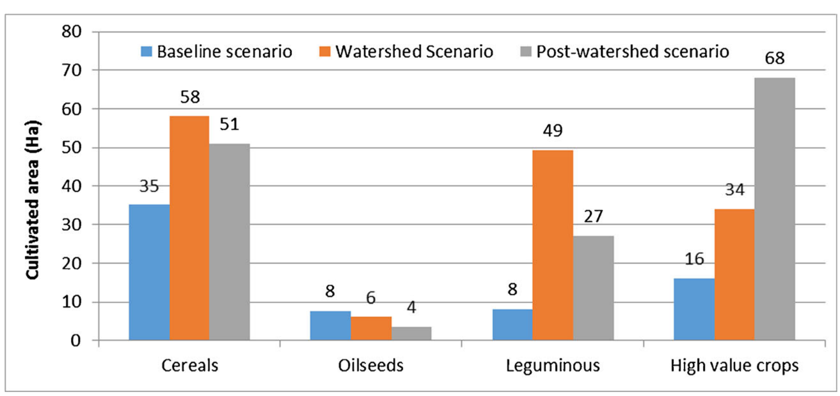
Returns to land

The positive gross margins as well as positive returns to factors of production are the real testimony for sustainability of agriculture development. The returns to land are expressed as US$ per ha and presented separately for different crop categories during the watershed and post watershed intervention period. Figure 4 shows that during the watershed intervention period, farmers with different crops realized returns to land amounting to US $720 ha^{-1} from cotton, $295 ha^{-1} from flowers, $287 ha^{-1} from vegetables and $171 ha^{-1} from cereals. However, the returns to land seem to be on a declining trend during post-project intervention. Nevertheless, such returns to land do not vary much from each other because during the year with normal rainfall, the runoff is able to reach the end plots and subsidizes all other requirements. The overall average returns to land of $234 ha^{-1} was realized during the watershed intervention period and it was the same even during the post-project period. Such a level of 'return to land' is substantial in the context of rural economies and raises the possibility that the watershed intervention has built resilience into the cropping system, which may cushion it against risks from climate change.

Returns to labour

Returns to labour reflect the level of reward for each person-day of the household workforce engaged in the production process. In income-poverty analysis, return to labour indicates the magnitude of daily income that can be gauged on absolute poverty thresholds to reflect the depth of poverty. Figure 5 shows that irrespective of crop strategies, farmers realized positive returns to labour during both watershed and post-watershed periods. Farmers who have adopted cotton realized

Fig. 2 Area under cultivation of major food and cash crops during different phases of watershed implementation in Adarsha watershed, Kothapally, Telangana



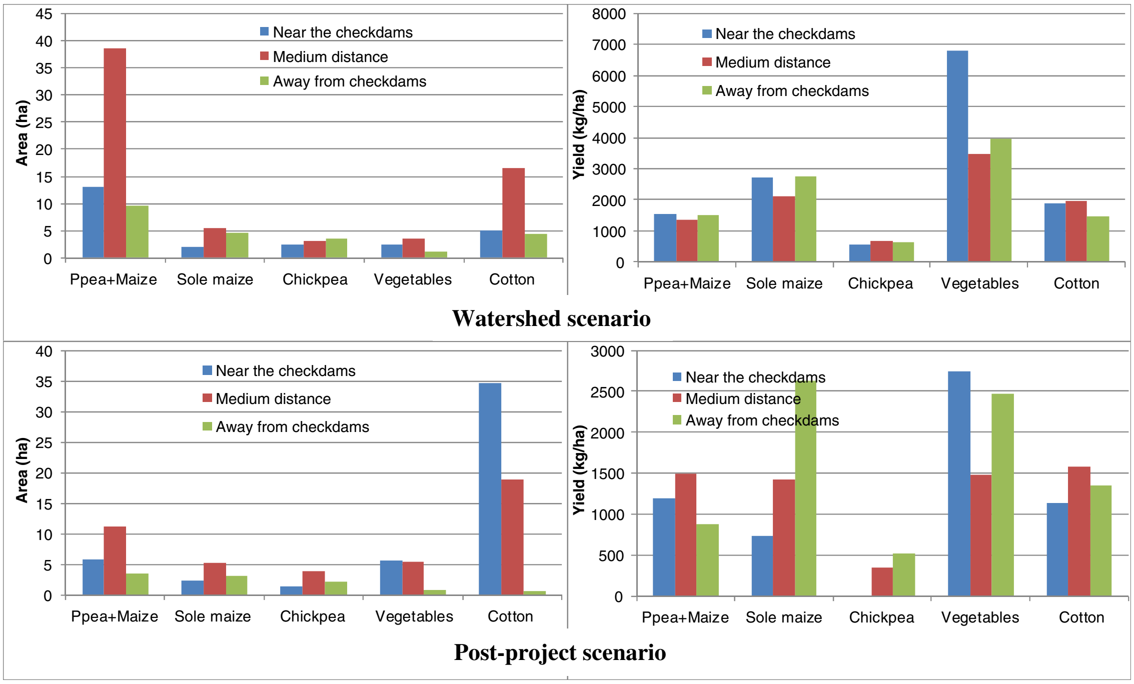


Fig. 3 Impact of water harvesting structures on area expansion and yield of different dryland crops in Adarsha watershed, Kothapally, Telangana

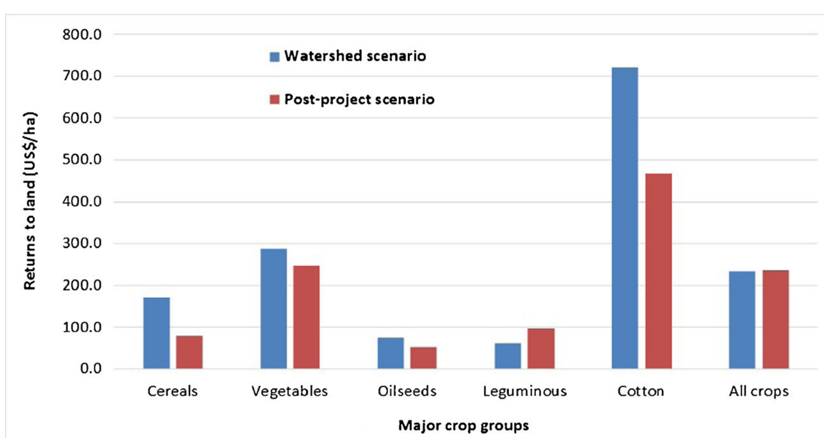
higher returns both during and after the watershed intervention. The returns per person-day from cereals showed a declining trend, whereas vegetables and leguminous crops brought increasing returns. The overall mean returns to labour irrespective of crop strategies was $10 per person-day. As such, the level of return to labour is 10 times above the global poverty line of $1 per person day, reflecting the positive impact of watershed intervention on poverty reduction.

Building resilience through an integrated approach

As in most developing countries, revenues from agricultural production are only one of several possible sources of income. Diversification of livelihood strategies is a common practice for spreading and hence reducing risk. An analysis of household income shares indicated the extent to which farmers are dependent on subsistence crops, combined with the other sources.

Watersheds help farmers to build resilience during drought years by sustaining crop income – a major indicator of food security. We can observe a clear system of diversification in watershed and non-watershed areas as around 50 % of household income was derived from outside the farm economy. The contribution of non-farm income is even higher (around two-thirds share of total income) in non-watershed areas during drought years as there is little scope for farm activities, unlike in watershed areas. Crop income, which is a major source of food security in rural areas, contributes less than 50 % both in watershed and non-watershed areas. However, watershed has contributed to improved resilience of agricultural income despite the severe

Fig. 4 Returns to land in the production of major dryland crops in Adarsha watershed



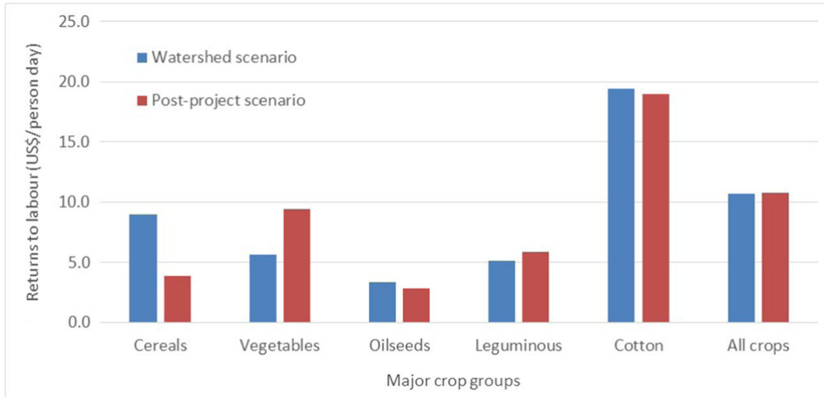


Fig. 5 Returns to labour in the production of major dryland crops in Adarsha watershed

drought during 2002 in the watershed area. Whilst drought induced shocks reduced the average share of crop income in the non-watershed area from 44 to 12 %, this share remained relatively unchanged at about 36 % in the watershed area. The livestock sector also contributed significantly to total household income in watershed villages even during droughts (Fig. 6).

Therefore, it is imperative that watershed management should be implemented in dryland areas as a sustainable adaptive mechanism, especially in drought-affected areas. With appropriate investment in farming practices, rural communities can do much to protect their agricultural productivity in the face of climate change.

Conclusions

In rainfed areas, integrated watershed management can contribute significantly to the improvement of livelihoods. Watershed intervention has the potential for poverty reduction by giving impressive returns to land and labour even during drought years. The yields of important crops in this study were above the norm but realized low prices owing to lack of effective market demand for the products. This suggests that tremendous economic benefits could be reaped from market oriented development of robust and sustainable watersheds. The new generation of watershed interventions emphasizes achieving food and income security of farmers while maintaining the integrity of the eco-hydrology and other natural systems.

Integrated Watershed Management Projects (IWMP) enabled farmers to increase yields of dryland crops such as maize, pigeonpea and sorghum and increase cropping intensity by enabling them to grow chickpea in the post-rainy season. Maize and paddy are major food crops during the kharif season and maize intercropped with pigeonpea produced yields in excess of 2 t ha^{-1} during the watershed intervention period. With improved management practices coupled with seeds of high yielding varieties and supplementary irrigation, high yields can be obtained from dryland crops.

Increased water availability resulted in diversification with high-value crops such as vegetables and Bt cotton. Cotton is the major commercial crop grown in this region fetching high market prices and consequent profits. Cotton, along with vegetables, gave much higher returns to land and labour compared to other crops, both during and after watershed

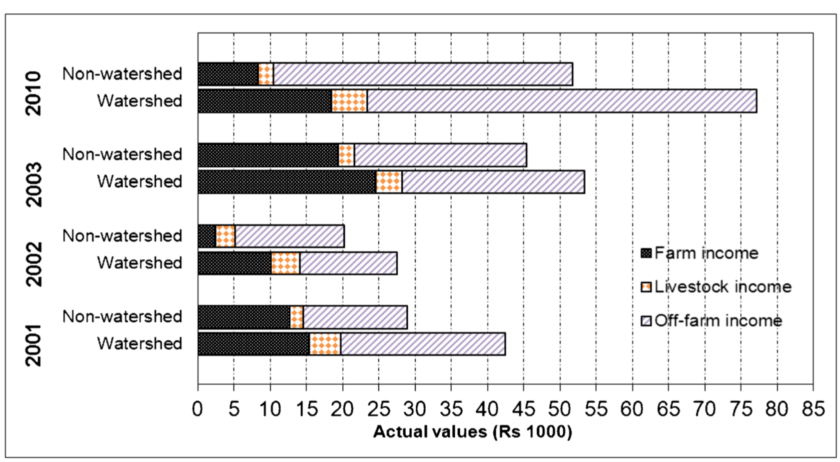


Fig. 6 Impact of watershed development on household income in Adarsha watershed

intervention. Thus, such interventions are able to increase physical yields of food and commercial crops resulting in tremendous financial earnings in the watershed.

IWMP interventions built resilience in the village during the drought years and maintained the share of agricultural income constant in total family income whereas non-watershed village farmers had to migrate for livelihoods as the share of agricultural income was reduced drastically to 12 %. Livestock is an important source of livelihoods in rainfed areas and efforts to improve its productivity in the watershed paid rich dividends.

There was considerable consistency in the returns to land and labour during watershed and post-watershed periods. Watershed intervention is an essential strategy in the semi-arid tropics for enhancing crop productivity and sustaining rural livelihoods. Additionally, in the case described in this paper, the intervention has also brought sustainability in crop economy by introducing improved water and soil conservation and techniques such as balanced fertilizer application, use of improved seeds, supplementary irrigation and crop diversification.

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