Research Article

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Enhancing agricultural productivity and rural incomes through sustainable use of natural resources in the Semi Arid Tropics

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Abstract

BACKGROUND: A participatory watershed management approach is one of the tested, sustainable and eco-friendly options to upgrade rain-fed agriculture to meet growing food demand along with additional multiple benefits in terms of improving livelihoods, addressing equity issues and biodiversity concerns.

RESULTS: Watershed interventions at study sites in Thailand (Tad Fa and Wang Chai) and India (Kothapally) effectively reduced runoff and the associated soil loss. Such interventions at Xiaoxincun (China) and Wang Chai improved groundwater recharging and availability. Enhanced productive transpiration increased rainwater use efficiency for crop production by 13–29% at Xiaoxincun; 13–160% at Lucheba (China), 32–37% at Tad Fa and 23–46% at Wang Chai and by two to five times at Kothapally. Watershed interventions increased significantly the additional net returns from crop production as compared with the pre-watershed intervention period. Increased water availability opened up options for crop diversification with high-value crops, including increased forage production and boosted livestock-based livelihoods.

CONCLUSION: In dryland tropics, integrated watershed management approach enabled farmers to diversify the systems along with increasing agricultural productivity through increased water availability, while conserving the natural resource base. Household incomes increased substantially, leading to improved living and building the resilience of the community and natural resources.
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Keywords: dryland agriculture; natural resource management; watershed; water productivity; resilience; China; India; Thailand

INTRODUCTION

Watersheds as entry points for sustainable productivity and resilience in rainfed agriculture

Erratic rainfall, land degradation, soil erosion, poverty and burgeoning population characterize the dry regions in Asia, which are further strengthening the nexus between poverty and environmental degradation.[1] Depletion of the resource base is diminishing the capabilities of poor farmers to earn more and making them vulnerable to drought and other climate-related disasters. Meeting the Millennium Development Goal of halving the number of poor people by 2015 is becoming a daunting challenge for planners and policy makers. A recent global assessment of Water for Food and Water for Life indicated that the goal of food security can be met with the available water resources only with drastic and urgent changes in the way we produce food worldwide,[2] more so in the developing arid, semi-arid, sub-humid and humid tropics. There is an urgent need to harness the vast untapped potential of rainfed agriculture in Asia and Africa by substantially boosting financial and technical investments in these regions.[3] Current yield levels in rainfed farmers' fields are lower by two- to four folds than the achievable yields, requiring technologies, institutions and policies to bridge the yield gap.[4–8] These areas witness acute moisture stress during critical stages of crop production, which make agriculture production vulnerable to pre- and post-production risks. Development of the watershed/catchment is one of the most trusted and eco-friendly approaches to managing rainwater and other natural resources, which has paid rich dividends in rain-fed areas and is capable of addressing many natural, social and environmental intricacies.[4,6,7,9,10] Management of natural resources at the catchment/watershed scale produces multiple benefits in terms of increasing food production, improving livelihoods, protecting the environment, addressing gender and equity issues along with biodiversity concerns,[4,6–8,11] and is also recommended as the best option to upgrade rain-fed agriculture to meet the growing food demand globally.[4,12] Therefore, with a view to evaluating and developing sustainable natural resource management options for increasing agricultural productivity and income of the rural poor in dry regions of Asia, the present study pursued an

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Table 1. Summary of multiple benefits derived from watersheds in India

Parameter	Particulars	Unit	No. of studies	Mean	Mode	Median	Min.	Max.	*t*-value
Efficiency	B : C ratio	Ratio	311	2.00	1.70	1.70	0.80	7.30	35.09
	IRR	Percent	162	27.40	25.90	25.00	2.00	102.70	21.75
Equity	Employment	Persons days ha^{-1} y^{-1}	99	154.50	286.70	56.50	5.00	900.00	8.13
Sustainability	Increase in irrigated area	Percent	93	51.50	34.00	32.40	1.23	204.00	10.94
	Increase in cropping intensity	Percent	339	35.50	5.00	21.00	3.00	283.00	14.96
	Runoff reduced	Percent	83	45.70	43.30	42.50	0.34	96.00	9.36
	Soil loss saved	t ha^{-1} y^{-1}	72	1.10	0.90	1.00	0.10	2.00	47.21

Source: Joshi *et al.*[13]

Integrated Farmer Participatory Watershed Management Model developed by ICRISAT in partnership with the national agricultural research systems (NARS) at selected benchmark locations in Asia.

Learning from watersheds in India

A summary of multiple benefits derived from watershed programs in India (Table 1) revealed that watershed projects yielded multiple exemplary benefits in terms of economics, sustainability and equity parameters. In terms of efficiency, the watershed program performed well, with a mean benefit–cost ratio (BCR) of 2, which indicated that investments in watershed programs are economically viable and substantially beneficial. However, the performance of the watershed in accordance with their BCR was quite varied. About 32% of the watersheds generated a mean BCR above 2 (Fig. 1), which indicated that the performance of 67% of watersheds could be improved substantially.[13] Merely 0.6% watersheds failed to be commensurate with the investments. The mean internal rate of return (IRR) of 27.4% on watershed investment shows marginal efficiency of the projects. However, this seems to be high and indicates that investment in watershed programs is comparable with any successful government programs. It is interesting to note that about 27% of watersheds yielded an IRR above 30%. Watersheds with IRR $<10\%$ were only 1.9% (Fig. 1). These results reconfirm that watershed projects are economically viable and generate substantial economic, social and environmental benefits, and justify the investment in watershed programs as income levels were raised within the target domains.

Further, the benefits from watershed programs in India were conspicuously more in the low-income regions (B : C ratio of 2.46; 175 person days ha^{-1} y^{-1} employment generation) as compared with the high-income regions (B : C ratio of 1.98; 132 person days ha^{-1} y^{-1} employment generation).[13] This suggests that watershed programs should receive high priority by the governments in medium- and low-income regions.

Realizing untapped yield potential in the rainfed Semi Arid Tropics (SAT)

A long-term study since 1976 at the ICRISAT center based at Patancheru, India, demonstrated a virtuous cycle of persistent yield increases through improved land, water and nutrient management in rainfed agriculture. An improved system of sorghum/pigeon pea intercropping produced 5.1 t ha^{-1} grain yield compared with 1.1 t ha^{-1} with sole sorghum (Fig. 2) in the traditional system.[6]

Eighty per cent of the cultivated area worldwide is rainfed and contributes nearly 60% of the world's food. These regions are

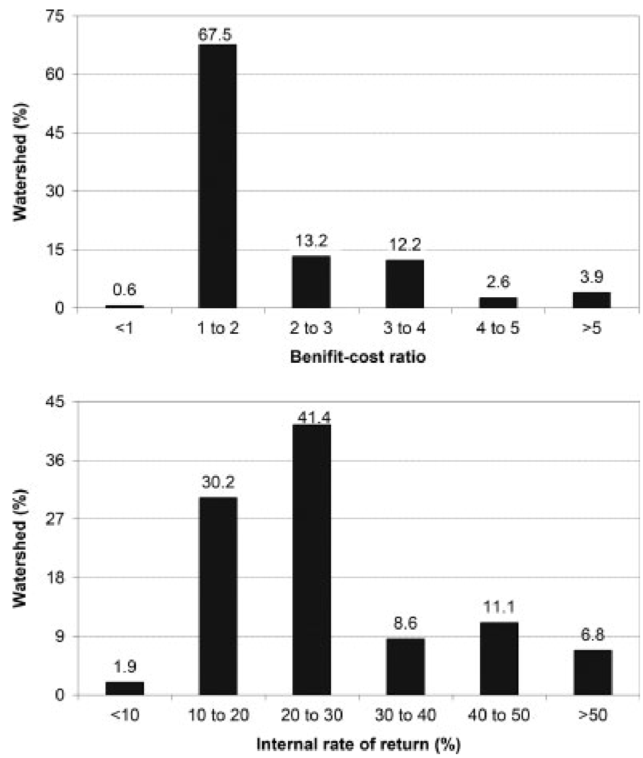

Figure 1. Distribution (%) of watersheds according to (top) benefit–cost ratio, (bottom) internal rate of return. Source: Joshi *et al.*[13]

home to the world's poor and malnourished people, and almost all population growth (95%) is taking place in these developing regions. The actual yields from rainfed agriculture are quite low, as compared to achievable ones in semi-arid tropical agro-ecosystems (Figs 2 and 3). In countries in eastern and southern Africa the yield gap is very large. In many countries in west Asia, farmers' yields are less than 30% of achievable yields, while in some Asian countries the figure is close to 50%. Historic trends present a growing yield gap between farmers' practice and farming systems that benefit from management advances. The large gaps between actual and attainable yields suggest an untapped potential for yield increase to feed the burgeoning population.

The present scenario thus clearly points to the need for adoption of science-led interventions leading to efficient and sustainable use of natural resources to improve agricultural productivity and livelihoods to alleviate poverty, hunger and malnutrition in SAT regions.

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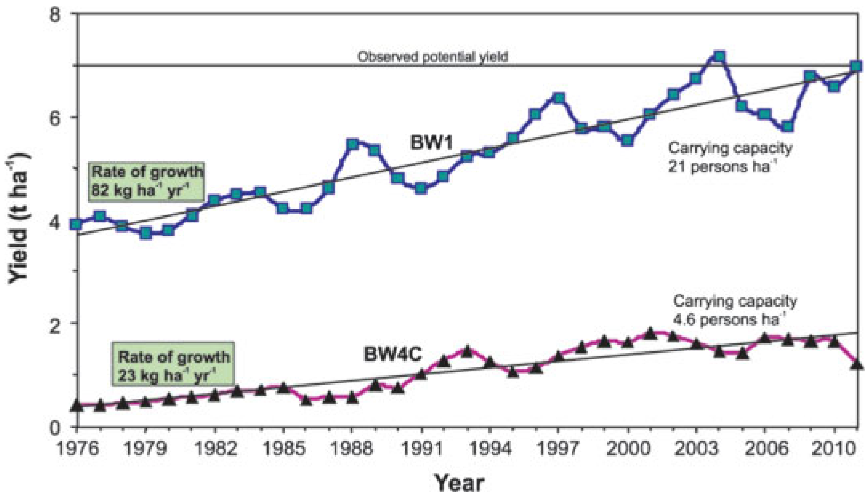

Figure 2. Three-year moving average of crop yields in improved and traditional management systems during 1976–2010 at ICRISAT, Patancheru, India. Source: Wani *et al.*[6]

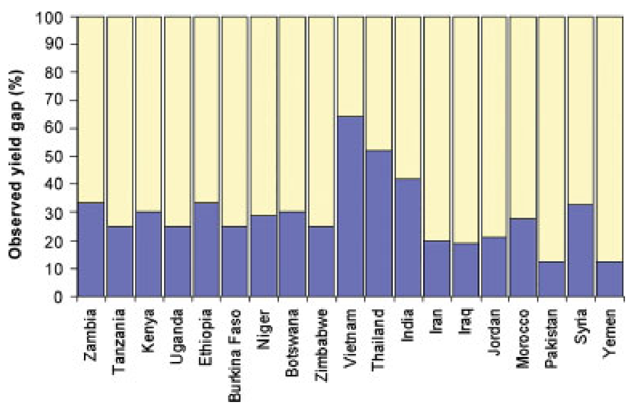

Figure 3. Observed yield gaps (for major grains) between farmers' yields and achievable yields (100% denotes achievable yield level, and columns actual observed yield levels). Source: Rockstrom *et al.*[4]

MATERIALS AND METHODS

Details of case study watershed sites

The details of sites of farmer participatory watershed management programs managed and evaluated by ICRISAT as a consortium partner in China, India and Thailand are given in Table 2.

The major constraints for crop production in general were lack of water due to low and erratic rainfall and frequent droughts. Soil degradation was equally a major problem particularly in China due to associated soil erosion which had caused large gullies. Farmers in the watersheds were resource poor and with little awareness to take on the emerging challenges.

Participatory and consortium approach

As reported earlier, analysis of performance of the watershed programs in India showed great scope for enhancing the impacts of watershed development. In order to ensure tangible benefits for smallholders and landless, a participatory watersheds approach was used as an entry point for improving livelihoods rather than only focusing on soil and water conservation, as was the case traditionally.[7,14] The major component of the participatory watershed approach comprised the collective action by farmers and their participation from the beginning through cooperative and collegiate mode in place of contractual mode. To bring in equity for small farmers, a focus on demand-driven low-cost technologies with built-in tangible economic benefits comprised an integral component of participatory watersheds which particularly ensured increased individual participation. In a survey, 70% of the population felt involved from the initial stage and the same percentage of the population showed attendance at all meetings. Twenty seven percent of the population felt involved in decision making and a fairly high 83% felt involved in the performance of allocated tasks. Empowerment of the community in decision making and execution of tasks brought in the ownership which constituted the bottom line for success in watershed interventions. The ownership helped develop watershed as an institution to ensure that users pay without free rides, and thus introduced a component of sustainability after cessation of external aid in the participatory watershed programs.

A consortium of experts from different institutions supported farmers in taking forward the watershed programs at study sites in different countries. In the case of Chinese watersheds (Xiaoxincun and Lucheba), the consortium comprised ICRISAT, Patancheru; the Integrated Rural Development Center of Guizhou Academy of Agricultural Sciences (GAAS), Guizhou; and the Tropical and Subtropical Cash Crops Research Institute of Yunnan Academy of Agricultural Sciences (YAAS), Kunming. For Thai watersheds (Tad Fa and Wang Chai), the consortium comprised ICRISAT; Royal Thai Department of Agriculture; Royal Thai Department of Land Development; and Khon Kaen University. In the Indian watershed at Kothapally, the consortium comprised ICRISAT; the Central Research Institute for Dryland Agriculture (CRIDA); the National Remote Sensing Agency (NRSA); State Government Department on Drought Prone Area Program; and the M Venkatarangaiya Foundation (non-governmental organization).

IGNRM and livelihood interventions

Demand-driven and site-specific integrated genetic and natural resource management (IGNRM) and livelihood interventions constituted the core of watershed programs at different study sites. The prominent interventions are detailed in Table 3. Both the Chinese watershed programs were initiated during 2003 under the second phase of the Asian Development Bank (ADB)-supported project. In Thailand, the Tad Fa watershed program was initiated

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Table 2. Details of case watershed sites in China, India and Thailand

Site	Region	Geographic position	No. of families	Rainfall (mm)	Soil type	Major crops/cropping systems
Xiaoxincun	Yunnan province, China	25° 36′ 14″ N/103° 13′ 12″ E	86	640	Ultisols; inceptisols	Rice – vegetables (broad bean, chillies), corn, groundnut, sweet potato, watermelon
Lucheba	Guizhou province, China	26° 35′/106° 43′	365	1284	Ultisols; inceptisols	Rice, corn, rape, soybean, sunflower, kidney bean, cabbage, watermelon and vegetables (tomato, pumpkin, chillies, eggplant etc.)
Kothapally	Andhra Pradesh, India	17° 20′ – 17° 24′ N/78° 5′ – 78° 8′ E	270	800	Vertisols; vertic inceptisols	Sorghum, pigeon pea, blackgram, maize, paddy, cotton, sunflower, vegetables
Tad Fa	Khon Kaen Province, Thailand	15° 30′ N/101° 30′ – 140° 30′ E	358	1300	Ustults	Maize, vegetables, bamboo plantation, tamarind orchard
Wang Chai	Khon Kaen Province, Thailand	16° 30′ N; 102° 47′ E	358	1171	Ustults	Paddy, groundnut, soybean, sugarcane, cassava, cowpea, vegetables, fruits

in 1999 and the Wang Chai watershed in 2003. In India, the Kothapally watershed program started in 1999 as one of the three benchmark sites in India. The post-intervention impact was recorded at different locations 3–5 years later.

Data sources and methodology

The study recorded the pre-intervention/pre-project (during the project starting year) baseline data and a post-intervention/post-project impact due to the watershed programs. The post-intervention impact was recorded during 2005 on crop productivity, rainwater use efficiency (RWUE) and runoff in Xiaoxincun, Lucheba and Wang Chai watershed sites, and on forage production- and livestock-based livelihoods at the Lucheba site. Similarly, the impact on crop productivity, RWUE and runoff was recorded in Tad Fa during 2004. The impact on groundwater level was measured during 2006 at Xiaoxincun and Wang Chai locations as compared to that at the inception of watershed programs in 2003. Income stability and resilience effects were studied at Kothapally during the drought year 2002 as compared with the normal year 2001.

This study is based on primary as well as secondary data collected from the watersheds. The water balance, storage capacity of water-harvesting structures and crop yields were calculated using standard methods. Rainwater use efficiency was calculated as kilograms of agricultural product produced per millimeter of rainfall per hectare (kg mm^{-1} ha^{-1}). Other financial details were collected from the Project Implementing Agency (PIA). Impact assessment of investment on watershed interventions was also carried out to examine the efficiency of economic returns, etc. The primary data for this were collected from 30% households/farmers selected with a stratified random sampling method by using a pre-tested set of questionnaires through focus group discussions (FGD) and a stratified detailed household survey and verified by field visits. The objectives of the study were explained to the farmers before conducting the survey. The secondary data were collected from various sources, mainly progress reports and others. All the primary and secondary data collected for this study were thoroughly checked to make sure they were free from errors or discrepancies.

RESULTS AND DISCUSSION

Water balance

The study on water balance at Tad Fa watershed in Thailand during the wet year 2000 (Fig. 4) showed more rainfall than the potential evapo transpiration (PET) from the first week of April until the last week of October. During this period there were times when rainfall was less than the PET, but the soil had reached field capacity by the last week of April and so surplus water started accumulating for use in crop growth. Annual water surplus during 2000 was 1240 mm; however, a 352 mm annual water deficit was experienced during the dry period of the year.

On the other hand, during the dry year 2001, rainfall surpassed PET from the last week of April and this continued up to the middle of September only (Fig. 4). A meager water surplus of 77 mm was observed during 2 weeks of the year only. There was a considerable annual water deficit of 578 mm.

Similarly, the Xiaoxincun watershed in China showed a high annual PET of about 1464 mm compared to the rainfall of 640 mm, with a large water deficit (Fig. 5). Xiaoxincun experienced very little water surplus for a short duration in the rainy season only,

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Table 3. Prominent watershed interventions at different study sites

Site	Water conservation and harvesting measures	Landform management	Crop diversification and forage production	Biomass generation, recycling and vermicomposting for soil fertility	Best production practices
Xiaoxincun, China	Water-lifting infrastructure from nearby Longchuanjiang River to cement tank (600 m^3 storage capacity) for community irrigation purpose; construction of earthen tank and check dams; repair and desilting of water channel and rejuvenation of existing tanks	Contour cultivation (>80% farmers)	Improved grass planting on slopy lands; crop diversification to high-value crops	Biomass generation and recycling through *Gliricidia* plantation (1000 saplings at 95% survival) on bunds; biogas (80 plants) slurry	Soil test-based fertilizer management (STBFM), which included deficient K as well
Lucheba, China	Rainwater harvesting through 151 small masonry water tanks of 5 m^3 capacity	Contour cultivation	Diversification to vegetables and other crops (area under vegetables was 30 ha in 2003, which increased to 80 ha in 2005; area under watermelon cultivation was 10 ha in 2003, which increased to 33 ha in 2005); increased forage production and livestock-based livelihoods, which also promoted biogas plants	Biogas (200 plants) slurry	STBFM, which included deficient K; integrated pest management (IPM) measures including insecticidal lanterns
Kothapally, India	14 water storage structures (1 earthen and 13 masonry) with a capacity of 300–2000 m^3 were constructed; 97 gully control structures; 60 mini-percolation pits; 1 gabion structure for increasing groundwater recharge; a 500 m long diversion bund and field bunding on 38 ha were completed	Broad-bed and furrow (BBF) landform; contour cultivation	High-value vegetable cultivation	*Gliricidia* plantation on field bunds to supply nitrogen-rich organic matter for *in situ* application to crops; vermicomposting	Use of Tropicultor for planting; IPM; STBFM
Tad Fa, Thailand	Construction of 17 farm ponds each of 1260 m^3 capacity; field bunding; conservation agriculture on steep slopes	Contour cultivation	Crop diversification including fruits	Crop residue incorporation	Improved cultivars; STBFM; low-cost IPM
Wang Chai, Thailand	Construction of 39 farm ponds each of about 1250 m^3 capacity; field bunding; vegetative barriers	Drains for disposal of excess water; contour cultivation	Crop diversification to high-value crops; vetiver grass (*Vefiveria nemoralis*) planting on field bunds	Enriched vermicompost	Improved cultivars; integrated nutrient management; IPM; value addition of crop produce

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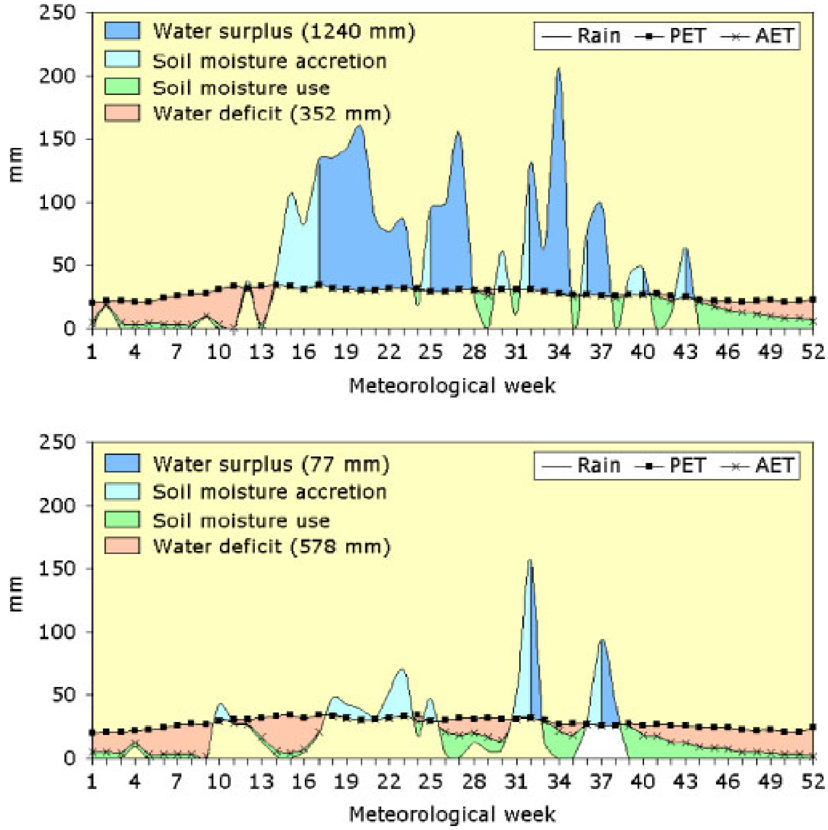

Figure 4. Water balance in Tad Fa watershed, Thailand. Top: data for year 2000 (wet year); bottom: data for year 2001 (dry year).

suggesting that *in situ* rainwater conservation measures would be economically more remunerative and investments in *ex situ* harvesting could be moderate.

The water balance at Lucheba watershed in China, however, revealed a lower annual PET of 891 mm compared to its annual rainfall of 1284 mm and thus a large water surplus, particularly during June and July (Fig. 5).

The studies on distribution of various water balance elements clearly demonstrated uneven distribution of rainfall during the year and indicate the need to adopt measures for efficiently harnessing and conserving surplus water during rainy periods to effectively increase resilience to counter water deficits, particularly during dry periods of the year or in a dry year itself.

Reduced runoff and soil loss

Improved watershed management by way of constructing water-harvesting structures, cultivation across the slope, planting of *Gliricidia* on the bunds, less exposed soil due to increased cropping intensity, increased use of organic manures, and better crop growth due to adoption of balanced nutrition resulted in restriction to free flow of water, leading to more infiltration and thereby gave reduced runoff in comparison to the rainfall received (Table 4). The reduced runoff which infiltrates into the soil will apparently strengthen the green water sources in rainfed agriculture, the consumption of which is almost threefold more than blue water consumed (5000 *versus* 1800 km^3 y^{-1}) for food production.[15] Soil erosion, which is a major environmental problem particularly in Yunnan province of southwest China,[16] and other parts of the SAT including the benchmark site Tad Fa in northeast Thailand, will be decreased due to improved watershed measures which apparently restricted displacement of soil particles and loss with the reduced runoff water.

Improved groundwater recharge

The impact of watershed interventions was recorded as improvement in the groundwater availability at the Xiaoxincun watershed location. Of 80 open wells, 40 situated in the middle toposequence and used for drinking purposes, and another 40 situated in the lower toposequence and used for irrigation purposes, showed a rise in the water table (Fig. 6). The mean rise in water table of 3.8 m was observed (13.9–10.1 m) in wells meant for irrigation and of 1.4 m (23–21.6 m) in wells meant for drinking purposes. The results are expected due to the watershed interventions, which reduce runoff and promote infiltration and recharging of groundwater. In recent years, the groundwater in China, particularly in western parts, has been exploited on a large scale, leading to a decline of groundwater,[17] so the present results are quite encouraging in the context of arresting declining groundwater levels.

Similarly, in Wang Chai, Thailand, the water column in farm ponds increased by 0.8 m during dry months, 1.6 m during wet months, and overall on an average by 1.2 m in the post-project period as compared with the pre-project period (Fig. 6).

Agricultural productivity, rainwater use efficiency and profitability

As a result of watershed interventions, the water use efficiency by different crops at Xiaoxincun location increased by 15–29%, which brought in substantial productivity improvement (Table 5), resulting in higher profit margin. The watershed interventions, which improve substantially the green water resources, apparently

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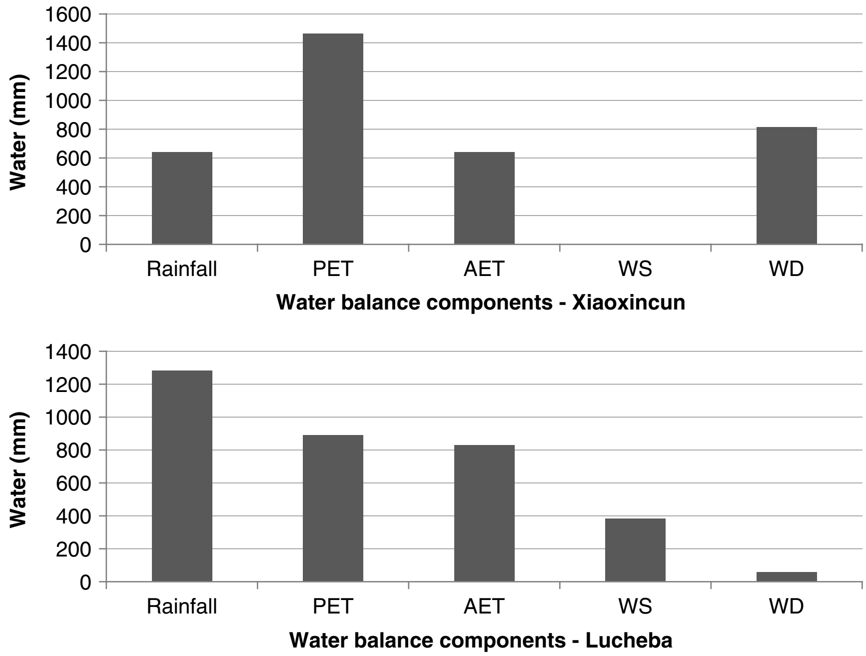

Figure 5. Water balance components of watershed. Top: Xiaoxincun, China; bottom: Lucheba, China.

Table 4. Impact of improved watershed management on reducing runoff water

Country	Study site	Rainfall (mm)	Runoff (mm)	Runoff as % of rainfall
China	Xiaoxincun	612	97.3	15.9
India	Kothapally	743	44	7.8
Thailand	Tad Fa	1284	169	13.2
	Wang Chai	940	210	22.3

led to better utilization of available water resources in productive transpiration and resulted in more food per drop of water. The results proved that 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,[5] is effectively addressed through participatory watershed interventions. The net benefit after watershed interventions increased by 550 renminbi (RMB) (US \$69) ha^{-1} in rice, 880 RMB (US \$111) ha^{-1} in maize, 1700 RMB (US \$215) ha^{-1} in groundnut, 2800 RMB (US \$355) ha^{-1} in watermelon and 2250 RMB (US \$285) ha^{-1} in sweet potato. In addition to long-term sustainable benefits, crop production with watershed intervention is also a profitable option in terms of benefit: cost ratio.

As with the Xiaoxincun site, the watershed interventions at Lucheba also recorded enhanced rainwater use efficiency (13–160%) in crop production, which resulted in considerable productivity improvement (Table 5). The runoff water harvested in tanks facilitated supplementary irrigation at critical stages and brought a change in production scenario. The net monetary advantage increased after watershed interventions by 9250 RMB (US \$1171) ha^{-1} in vegetables and by 5250 RMB (US \$665) ha^{-1} in watermelon production.

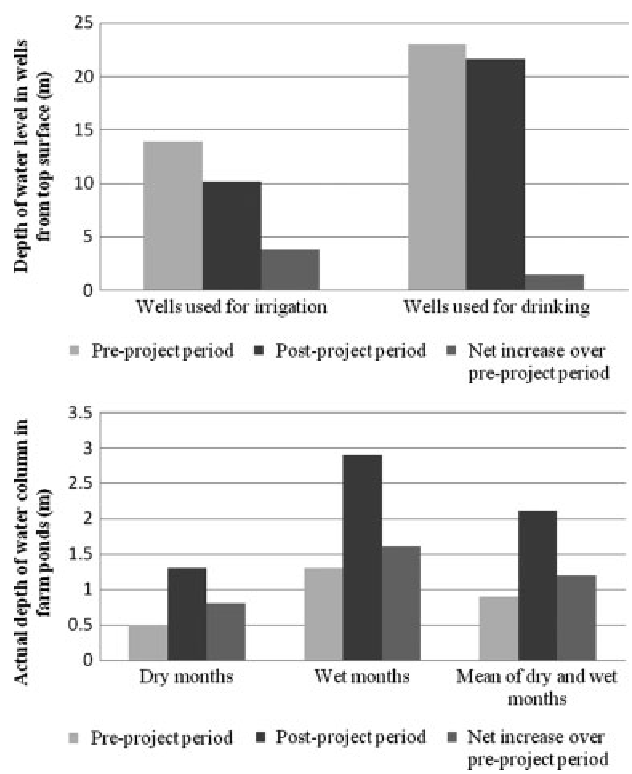

Figure 6. Impact of watershed interventions on groundwater. Top: depth of water level in wells from top surface in Xiaoxincun, China; bottom: actual depth of water column in farm ponds in Wang Chai, Thailand.

At the Tad Fa study site in Thailand, the watershed interventions increased RWUE of maize and vegetables in the range of 32–37% (Table 6). The benefit–cost ratio of production increased by 17% in maize, 10% in cabbage and 15% in chillies. In monetary terms, the post-watershed intervention period showed 3470 Thai baht

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Table 5. Rainwater use efficiency (RWUE) and economics of crop production during pre- and post-watershed interventions in Xiaoxincun and Lucheba watershed, China

	Pre-project period				Post-project period			
Crop	Crop yield (kg ha^{-1})	RWUE (kg mm^{-1} ha^{-1})	Net income (RMB ha^{-1})	B : C ratio	Crop yield (kg ha^{-1})	RWUE (kg mm^{-1} ha^{-1})	Net Income (RMB ha^{-1})	B : C ratio
Xiaoxincun								
Rice	5 800	9.5	5 700 (US $722)	1.9	6 300	11.2	6 250 (US $791)	2.0
Maize	4 500	7.0	4 100 (US $519)	1.9	5 200	8.1	4 980 (US $630)	2.2
Groundnut	1 400	2.2	4 500 (US $570)	1.8	1 800	2.8	6 200 (US $785)	2.2
Watermelon	10 500	16.4	12 150 (US $1538)	3.4	12 500	19.5	14 950 (US $1893)	3.9
Sweet potato	19 500	30.4	10 425 (US $1320)	2.5	22 500	35.1	12 675 (US $1605)	3.0
Lucheba								
Vegetables	36 900	28.8	18 510 (US $2343)	1.4	41 900	32.6	27 760 (US $3514)	1.8
Watermelon	11 300	8.8	10 300 (US $1304)	1.5	29 300	22.8	15 550 (US $1969)	1.6

Table 6. Rainwater use efficiency (RWUE) and economics of crop production during pre- and post-watershed interventions in Tad Fa and Wang Chai watersheds in Thailand

	Pre-project period				Post-project period			
Crop	Crop yield (kg ha^{-1})	RWUE (kg mm^{-1} ha^{-1})	Net income (THB ha^{-1})	B : C ratio	Crop yield (kg ha^{-1})	RWUE (kg mm^{-1} ha^{-1})	Net income (THB ha^{-1})	B : C ratio
Tad Fa								
Maize	3 218	2.7	7 980 (US $222)	2.3	4 500	3.7	11 450 (US $318)	2.7
Cabbage	36 343	29.8	101 400 (US $2819)	3.9	49 063	40.2	139 220 (US $3870)	4.3
Chillies	2 406	2.0	67 420 (US $1874)	4.0	3 188	2.6	91 710 (US $2549)	4.6
Wang Chai								
Rice	1 500	1.3	5 800 (US $161)	2.4	2 200	1.9	8 880 (US $247)	2.8
Groundnut	950	0.8	7 250 (US $202)	1.8	1 200	1.0	9 450 (US $263)	1.9
Sugarcane	5 500	4.7	920 (US $26)	0.6	6 800	5.8	1 350 (US $38)	0.8

(THB) (US $96) ha^{-1} additional net income in maize, 37 820 THB (US $1051) ha^{-1} in cabbage and 24 290 THB (US $676) ha^{-1} in chillies as compared to pre-watershed interventions.

The other watershed location in Thailand at Wang Chai also showed a 23–46% increase in RWUE of rice, groundnut and sugarcane crops (Table 6). Benefit–cost ratio in the post-intervention period increased by 17% in rice, 6% in groundnut and 33% in chillies. The net additional income of farmers improved by 3080 THB (US $86) ha^{-1} in rice cultivation, 2200 THB (US $61) ha^{-1} in groundnut cultivation and 430 THB (US $12) ha^{-1} in sugarcane cultivation, as compared to the pre-intervention period.

Forage production and animal-based livelihoods

Increased water availability enabled farmers to increase cropping intensity and diversify to more remunerative land use systems involving horticulture, forage production on sloping lands, etc. In the study site at Lucheba watershed, the area under forage production increased from 8.4 ha in 2003 to 15.7 ha in 2005 (Table 7), which resulted in the twin benefits of arresting soil erosion from sloping lands and increased forage supplies for animal-based livelihoods. The maximum area under forage crops was under rye (85%), followed by alfalfa (13%).

Livestock and ruminants are important components of the farming system and provide an alternative source of income and livelihoods, in addition to improving resilience to shocks. The holistic watershed interventions increased substantially the livestock population and their productivity at Lucheba (Table 7) and other sites, and strengthened the alternative source of income, leading to enhanced resilience of the farming systems.

The substantial increase in animal population proved instrumental in promoting biogas plants for daily energy needs of households in watershed areas. Construction of biogas plants in Lucheba watershed area has reached more than 230 in the village. By switching over to biogas plants for meeting domestic energy requirements, one household saved about 690 RMB (US $87) per annum because of the cost of purchasing coal and saved 3–4 h for women per day needed for collecting fuel wood from the forest and protected trees. Similarly, biogas initiatives benefited more than 80 families in Xiaoxincun.

Socio-economic impact

The findings (Fig. 7) from the watershed site at Kothapally revealed that watershed interventions increased the resilience of the production systems and thereby ensured income stability during adverse climatic conditions.[8] During the drought year 2002, crop productivity and average incomes from the watershed area were far larger compared to the non-watershed area, and farmers in treated watershed area could meet their livelihood in the village, whereas in an untreated village a steep decline (44% to 12%) in the share of agricultural income in total income indicated that people relied on increased non-agricultural sources of income, i.e. through migration during the drought year.

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Table 7. Impact of watershed interventions on forage production development and livestock base livelihoods in Lucheba watershed, China

Year	Area under forage (ha)	Yield (t ha^{-1})	RWUE (kg mm^{-1} ha^{-1})	B : C ratio	Livestock population				
					Cattle (No.)	Pigs (No.)	Chicken (No.)	Duck (No.)	Goose (No.)
2003	8.4	36.9	28.7	1.4	195	512	738	251	120
2005	15.7	41.9	32.6	1.8	217	1017	1589	301	136

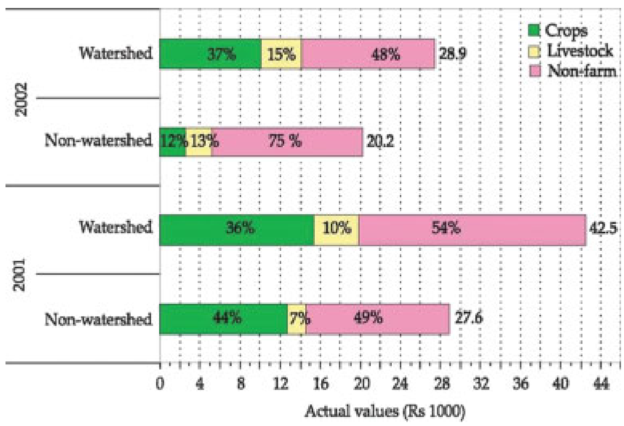

Figure 7. Income stability and resilience effects during a drought year (2002) in Adarsha Watershed, Kothapally AP, India, as compared to non-treated watershed village.

CONCLUSIONS

Participatory watershed management has put farmers in a central position to make decisions and ensure implementation through ownership of the same. The management of the benchmark watershed villages in China, Thailand and India, in line with watershed concepts, reduced land degradation and soil loss, improved water use efficiency, and enhanced agricultural productivity and incomes. The study concludes that watershed interventions contributed to raising income, generating employment and conserving the natural resource base. It is suggested that the watershed program could be a vehicle of development to alleviate poverty by raising farm productivity and generating employment opportunities while protecting the natural resources in marginal and fragile environments. Therefore, there is an urgent need to unify the efforts around a new paradigm, which shifts the objectives from merely drought proofing and agricultural production to sustainably increasing agricultural productivity, protecting the environment and building human and natural resource resilience to cope with future challenges, including climate change.

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