Community watersheds for food security and coping with impacts of climate change in rain-fed areas

Suhas P. Wani[a], Thawilkal Wangkahart[b], Yin Dixin[c], Zhong Li[d] and N.V. Thang[e]

[a]*Global Theme on Agroecosystems, International Crops Research institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India 502 324, s.wani@cgiar.org*
[b]*O/o Agricultural Research and Development, Khon Kaen, Thailand, oard3@yahoo.com*
[c]*Guizhou Academy of Agricultural Sciences(GAAS), Guiyang, Guizhou, China, yindixin@live.cn*
[d]*Horticultural Research Institute, Yunnan Academy of Agricultural Sciences, North Suburban, Kunming, Yunnan 65020, China, zhongli6605@vip.sina.com*
[e]*Vietnam Academy of Agricultural Sciences (VAAS),Hanoi, Vietnam, Thanglrdc@yahoo.com*

Abstract: *Food security, poverty, growing water scarcity, increased land degradation, loss of biodiversity are the major constraints for sustainable development in rain-fed areas; and the climate change will further impact exacerbate these through reduced length of growing period due to increased temperature and growing water scarcity.The current farmers' yields in the developing countries in dryland areas of the tropics are lower by 2 to 5 folds than the potential yields obtained by researchers and commercial farmers. The community watershed approach espouses the principles of convergence, consortium, collective action and capacity building to address the issues of equity, efficiency, economic gain and environment protection. This approach has been evaluated at a number of benchmark watershed sites in India, China, Thailand and Vietnam. Watershed management is seen as an entry point for improving livelihoods and achieving food security through diversification of the systems and enhancing agricultural productivity through efficient use of natural resources. Micro-enterprises for women and vulnerable groups created rural employment opportunities as well as additional sources of income. Capacity building is an important pillar for scaling-up this approach. This approach has resulted in increasing agricultural productivity by 2 to 3 folds, doubling the family incomes, and reducing runoff up to 66% and soil loss by 2/3rd.*

Keywords: *Rain-fed, Watershed, Livelihood, Rainfall variability, Resilience*

Introduction

In-spite of increased food production during last 50 years, 1.2 billion poor people are food insecure in the world. Food and feed demand is estimated to double in the next 50 years and with increasing population and urbanization in the developing countries such as India, these demands are not likely to be matched by food and livestock production with the current management practices (Rosegrant et al., 2002). Growing water scarcity and declining soil health are already complicating the national and global efforts to achieve food security in several parts of the world. Growing human population is reducing the per capita availability of land as well as water in different parts of the world.

Evidence is emerging that climate change is making the variability more intense with increased frequency of extreme events such as drought, floods and hurricanes (IPCC, 2007). A recent study with varying rainfall showed 10 to 20 per cent decrease in rain-fed production potential in the most vulnerable developing countries with an approximate potential of 1-3 billion people affected by 2080 (IIASA, 2002). Extreme events in the recent past in Andhra Pradesh, India such as 346 mm rainfall on 24 August 2000 with 178 mm in five hours at Kothapally watershed, a killer heat wave during May 2002 that has claimed more than 600 lives when maximum temperature reached to 51^0 C in West Godavari district as against of 41^0C, severe thunder storm activity at ICRISAT campus on 12th April, 2006 when temperature fell down by 12^0C in a just 15 minutes accompanied by high intensity rains of 16 mm in 15 minutes, 420 mm rainfall on 23trdJune, 2007 at Kurnool which was 60 per cent of mean annual rainfall are just few examples. Global warming and associated impacts of climate change will have adverse impact on water availability and food production and here again the developing countries in tropical regions are likely to be more adversely affected by the impacts of climate change.

Importance of Rain-fed Agriculture and Constraints

Rainfed areas in the developing world are the hot spots of poverty, malnutrition, water scarcity, severe land degradation. Farmers' crop yields in the rainfed areas are lower by two to five folds than the achievable yields (Rockstrom et al., 2007; Wani et al., 2006). Soil erosion and imbalanced use of nutrients in agriculture by the farmers' results in mining of soil nutrients and most of the hungry and malnourished people in the world are in rural Asia (Sanchez et al., 2005). In the semi arid tropics (SAT) of the developing world, poverty is concentrated more in the rain-fed areas (Ryan and Spencer, 2001). Drought and land degradation are interlinked with a cause and effect relationship and both in turn are the causes of poverty. Rain-fed agriculture is important as 80 per cent of the world's agricultural land area is rain-fed and generates 58% of the world's staple foods (SIWI, 2001); and also from the social and equity concerns, to meet the millennium development goal (MDG) of reducing the number of poor to half by 2015.

Potential of rain-fed agriculture

In tropical regions, particularly in the sub-humid and humid zones, agricultural yields in commercial rain-fed agriculture exceed 5-6 t ha-1 (Rockström and Falkenmark, 2000; Wani et al., 2003b, c). However, farmers' crop yields oscillate in the range of 0.5–2 t ha-1, with an average of 1 t ha-1 in sub-Saharan Africa, and 1-1.5 t ha-1 in the SAT Asia and Central and West Asia and North Africa (CWANA) for rain-fed agriculture (Rockström and Falkenmark, 2000; Wani et al., 2003a,b; Rockström et al., 2007). Evidence from long-term experiments at the ICRISAT center in Patancheru, India since 1976 demonstrated persistent yield increase through improved land, water, and nutrient management in rain-fed agriculture. Improved systems of sorghum/pigeonpea intercrops produced higher mean grain yields (5.1 t ha-1 per y) compared to 1.1 t ha-1 per y, average yield of sole sorghum in the traditional (farmers') post-rainy system where crops are grown on stored soil moisture (Fig. 1) with 5 t ha-1 farm yard manure once in two years. The large yield gap between attainable yield and farmers' practice showed that a large potential of rain-fed agriculture remained to be tapped. Yield gap analyses, undertaken for the Comprehensive Assessment (CA), for major rainfed crops in the semi-arid regions in Asia and Africa, and rainfed wheat in West Asia and North Africa (WANA), revealed large yield gaps, with farmers' yields being a factor 2–4 lower than achievable yields for major rain-fed crops grown in Asia and Africa (Rockström et al., 2007; Singh et al., 2009).

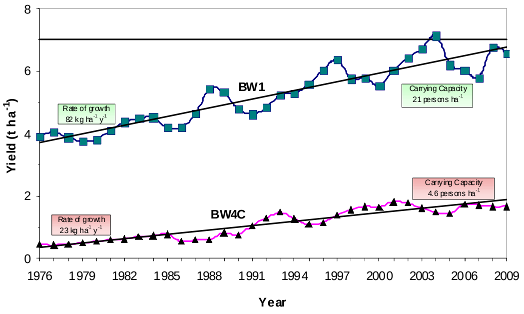


Figure 1. Three-year moving average of crop yields in improved and traditional management systems during 1976-2009 at ICRISAT, Patancheru, India.

Watersheds as growth engine for development of rain-fed areas: Experience in India

Watershed is a spatial unit, the water flowing through the watershed interconnects up-stream and down stream areas, provide life support to rural people creating interdependence between resources as well as resource users over time and space. Integrated watershed management (IWM) approach has continuously evolved in the country through new guidelines, policies, institutions, and expanding the scope (Wani et al., 2008, 2008a; Government of India 2008) and promoted as an appropriate strategy for improving productivity and sustainable intensification of agriculture in the rain-fed, drought-prone regions. Current watershed programs are much inclusive encompassing equity, gender, productivity enhancement, employment generation, income enhancement, soil and water conservation and most importantly to build the resilience to meet the challenges of future including climate change. Community-based IWM interventions created synergies between targeted technologies, policies and institutions that improve productivity, resource use sustainability and market access for the resource users (Wani et al., 2003c; Shiferaw et al., 2008).

A number of studies and their analysis showed that all has not gone well with the watershed programmes in India (Farrington and Lobo, 1997; Kerr et al., 2002; Wani et al., 2002, 2003; Joshi et al., 2005). Recent meta analysis of 636 case studies for the comprehensive assessment of watershed programs in India (Joshi et al., 2009) revealed that only <1 per cent of the projects were economically non remunerative (<1 B:C ratio) and 99% watershed projects were economically viable and productive with a benefit–cost ratio of 2.0 and the IRR of 27%. The watersheds also benefited farmers through enhanced irrigated areas by 51%, increased cropping intensity by 35.5%, reducing soil loss to 1.1 t ha^{-1} and runoff by 46%, and improved groundwater availability (Joshi et al., 2009). However, about 68% of the case studies showed a below average performance. (Fig. 2). The comprehensive assessment of watershed programs describes watershed development approach as growth engine of sustainable development in dryland areas and have recommended changes in watershed guidelines, policies and approach. The CA recommended that watersheds be developed as a business model through public private partnership mode and convergence of actors and programs with full community participation for enhancing crop productivity, income generation through targeted activities for small and marginal farmers, women, and vulnerable groups of the society, conserving natural resources and most importantly, building the resilience of natural resources and the community to cope with the future changes including climate change (Wani et al., 2008a).

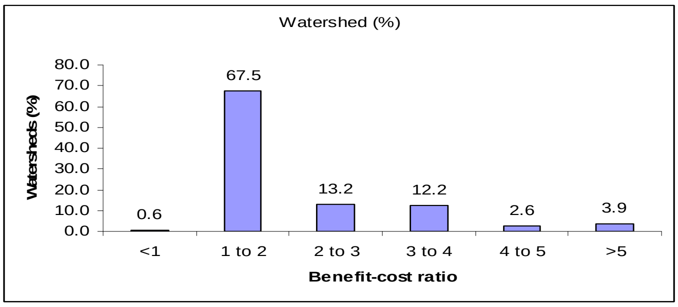
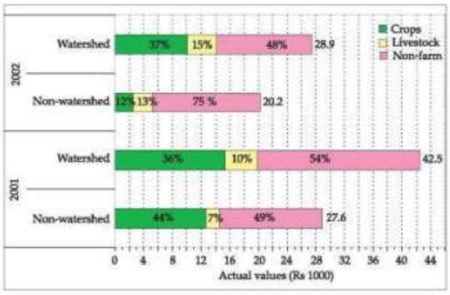


Figure 2. Distribution (%) of watersheds according to benefit-cost ratio (BCR) (Joshi et al., 2009).



New Paradigm in Community Watershed Management in Rain-fed Areas

Evidences collected during the CA of water for food and water for life, revealed that the business as usual approach in global agriculture would not be able to meet the goal of food security and reducing the poverty. If the situation continues, it might lead to crisis in many parts of the world (Molden et al., 2007). However, the world's available land and water resources can satisfy the future demands by upgrading rain-fed agriculture, discarding the artificial divide between rain-fed and irrigated agriculture, adopting integrated water resource management approach, investing in irrigation for expanding irrigation where scope exists, improving efficiency of the existing irrigation systems, conducting agricultural trade within and between countries, reducing gross food demand by influencing diets and reducing post-harvest losses, including industrial and household wastages. To upgrade the rain-fed agriculture in the developing countries, small watershed management by adopting community participatory and integrated approach is recommended and found effective through number of islands of success in Asia and Africa (Wani et al., 2002, 2003; Rockström et al., 2007; Wani et al., 2008).

The multidisciplinary team approach is not successful in agricultural research because of the perceived disciplinary hierarchy (Shambhu Prasad et al., 2005).The Community Watershed Consortium pursues knowledge and product integration of the various disciplines into useful extension messages for development workers that can sustain increased yields for a range of climatic and edaphic conditions. In Asia, an innovative and up-scalable watershed consortium approach uses rainwater management as an entry point activity starting with *in-situ* conservation and converting into tangible benefits with increased productivity. Integration of income-generating and sustainable crop and livestock production options of improved management of watershed landscapes is a live example of how the integrated approach led to significant benefits in poor areas (Table 1 and Fig.3).

Table 1. Average crop yields (Kg ha^{-1}) with equivalent of maize crop with different cropping systems at Adarsha Watershed, Kothapally, Andhra Pradesh, India,1999-2008.

Cropping systems	**Yield (Kg ha $^{-1}$)**												
	1999-2000	**2000-2001**	**2001-2002**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**Mean**	**CV%**	**SE±**
Improved Systems													
Sole maize	3250	3760	3300	3480	3920	3420	3920	3630	4680	4810	**3820**	**17.8**	**80**
Maize/pigeonpea intercrop system	5260	6480	5600	5650	6290	4990	6390	6170	6120	6680	**5960**	**16.7**	**116**
Sorghum/pigeonpea Intercrop system	5010	6520	5830	-	5780	4790	5290	5310	-	-	**5500**	**13.4**	**154**
Sole Sorghum	4360	4590	3570	2960	2740	3020	2860	2500	-	-	**3330**	**23.9**	**141**
Farmers practice													
Sole Maize	1700	1600	1600	1800	2040	1950	2250	2150	-	-	**1890**	**17.2**	**53**
sorghum/Pigeonpea intercrop system	2330	2170	2750	3190	3310	3000	3360	3120	-	-	**2900**	**19.2**	**110**
Hybrid cotton	2295	7050	6600	6490	6950	-	-	-	-	-	**5880**	**37.0**	**511**
BT cotton	-	-	-	-	-	-	6210	5590	7310	9380	**7120**	**26.1**	**315**
Mean	**3477**	**4970**	**3833**	**4018**	**4814**	**3651**	**4584**	**4320**	**6268**	**7396**			
CV%	**11.9**	**31.4**	**10.7**	**8.0**	**14.5**	**20.3**	**10.8**	**12.2**	**16.7**	**16.2**			
SE±	**415**	**1559**	**410**	**323**	**698**	**742**	**495**	**525**	**1049**	**1201**			

Note: In farmers practice Sorghum/Pigeon pea inter-crop system improved pigeon pea variety ICPL 87119 was grown along with local sorghum variety (Pacha Jonna) from 2001 onwards discontinuing the old variety which was highly wilt susceptible. In 1998 before the interventions sole maize yield was 1500 kg ha^{-1} and maize/pigeonpea yield (equivalent of maize was 1890 kg ha^{-1})

Figure 3. Effect of integrated watershed management on flow of household net income in Adarsha Watershed, Andhra Pradesh, India (Wani et al., 2008).

The households incomes and overall productivity had more than doubled throughout selected benchmark sites in Asia (Table 2). The benefits not only accrued to landholding households, but also to the landless marginalized groups through the creation of greater employment opportunities. The greater resilience of farmers in the watershed villages during the drought year 2002 was noteworthy.

Table 2. Annual water balance characters (all values in mm) in various watersheds in the SAT regions of Asia.

Country	Location	Rainfall	PET	AET	WS	WD
China	Xiaoxingcun	641	1464	641	Nil	815
	Lucheba	1284	891	831	384	60
Thailand	Wang Chai	1171	1315	1031	138	284
	Tad Fa	1220	1511	1081	147	430
Vietnam	Chine	2028	1246	1124	907	122
	Vinh Phuc	1585	1138	1076	508	62

India	Bundi	755	1641	570	186	1071
	Guna	1091	1643	681	396	962
	Junagadh	868	1764	524	354	1240
	Nemmikal	816	1740	735	89	1001
	Tirunelveli	568	1890	542	Nil	1347

Soil Health: An important driver for enhancing water use efficiency

ICRISAT on-farm diagnostic work showed declining soil health due to mining of nutrients resulted in the widespread (80-100%) multiple nutrient deficiencies of zinc, boron and sulphur (Table 3) along with thos of N and P (Rego et al., 2007; Sahrawat et al., 2007). To tackle this problem at least partly, farm bunds could be used for growing nitrogen-fixing shrubs and trees to generate nitrogen-rich lopping to augment soil organic matter. Growing *Glyricidia sepium* at a spacing of 75 cm on farm bunds could provide 28-30 kg nitrogen per ha in addition to valuable organic matter. Also, large quantities of farm residues and other organic wastes could be converted into nutrient-rich organic matter through vermicomposting. Legume-based systems particularly with pigeonpea could sequester carbon in the soil profile in Vertisols in the longer-term under rainfed conditions (Wani et al., 2003a). A substantial increase in crop yields and incomes through enhanced rainwater use efficiency were recorded with the addition of sulphur and micronutrients, and a further increase by 70 to 120% was obtained when S, B and Zn were added along with adequate N and P for a number of rainfed crops (maize, sorghum, mung bean, pigeonpea, chickpea, castor and groundnut) (Rego et al., 2005 and 2007).

Table 3. Percent farmers' fields deficient in plant nutrients in various states (districts within a state) of India[a] **Use SI unit**

State	No. of farmers' fields	OC (%)	AvP (mg kg^{-1})	K (ppm)	S (ppm)	B (ppm)	Zn (ppm)
Andhra Pradesh (Nalgonda, Mahabubnagar, Kurnool)	1927	84	39	12	87	88	81
Madhya Pradesh (Vidisha, Dewas, Guna, Badwani, Indore, Shajapur, Rajagarh, Raisen, Sehore, Sagar, Jhabua, Mandla)	73	9	86	1	96	65	93
Rajasthan (Bundi, Sawai Madhopur, Tonk, Jhalawar, Bhilwara, Alwar, Banswara)	179	22	40	9	64	43	24
Gujarat and Haryana (Bharuch Kutch, Gurgaon)	82	12	60	10	46	100	82
Tamil Nadu (Tirunelvelli)	119	57	51	24	71	89	61
Kerala	28	11	21	7	96	100	18
Karnataka (47 villages)*	17712	70	46	21	84	67	55

[a] OC = Organic Carbon; AvP = Available phosphorus

* Extensive soil sampling undertaken to interpolate the soil test results to the district level using GIS.

Water Resources Management is Critical in Rain-fed Areas

More than water quantity per se management of water resources is the limitation in the SAT regions. An analysis in Malawi indicates that over the past three decades, only a fraction of the years that have been politically proclaimed as drought years, actually were years subject to meteorological droughts (i.e. years where rainfall totals fall under minimum water needs to produce food at all) (Mwale, 2003).Even during drought years, watershed development efforts of improving rainfall management have benefited Indian farmers (Wani et al., 2006).

Evidence from water balance analyses on farmers' fields around the world shows that only a small fraction, less than 30% of rainfall, is used as productive green water flow (plant transpiration) supporting plant growth (Rockström, 2003). Weekly water balances of selected watersheds in Asia showed that potential evapo-transpiration (PET) varied from about 890 mm at Lucheba in China to 1890 mm at Tirunelveli in South India (Table 2). Actual evapo- transpiration (AET) values are relatively lower at the watersheds in China and India compared to those in Thailand and Vietnam.

Varying levels of water surplus (WS) and water deficit (WD) occurred in the watersheds. However, even in the most water deficit locations during the monsoon season, the nature of rainfall results in water surplus and provide an opportunity to conserve rainwater.

In the arid areas, typically as little as 10% of the rainfall is consumed as productive green water flow (transpiration), 90% flows as non-productive evaporation flow, i.e. no or very limited blue water generation (Oweis and Hachum, 2001). In temperate arid regions, such as WANA, a large portion of the rainfall is generally consumed in the farmers' fields as productive green water flow (45-55%) that results in higher yield levels (3-4 t/ha as compared to 1-2 t/ha) and 25-35% of the rainfall flows as non-productive green water flow and remaining 15-20% generate blue water flow. Low agricultural yields in rain-fed agriculture, often blamed as rainfall deficits, are in fact caused by other factors than rainfall. Still, what is possible to produce on-farm will not always be produced by resource-poor small-scale farmers due to other constraints.

Shifting non-productive evaporation to productive transpiration

Rainwater use efficiency in agricultural systems in the arid and SAT regions is 35 to 45%. This suggests scope for improvement of green water productivity, as it entails shifting non-productive evaporation to productive transpiration, with no downstream water trade-off. This *vapour shift* (or transfer) through improved management options is a particular opportunity in arid, semiarid and dry subhumid regions (Rockström et al., 2007). Field measurements of rainfed grain yields and actual green water flows indicate that by doubling yields from 1 to 2 t/ha in semiarid tropical agroecosystems, green water productivity may improve from approximately 3500 m^3/t to less than 2000 m^3/t. At low yields, crop water uptake is low and evaporative losses are high, as the leaf area coverage of the soil is low. This results in high losses of rainwater as evaporation from soil. When yield levels increase, shading of soil improves and evaporation from soil is minimized.

Discard artificial divide between irrigated and rainfed agriculture

Adopt integrated water resource management (IWRM) approach in the watersheds by discarding the artificial divide between rainfed and irrigated agriculture. There is an urgent need to have sustainable water use policies to ensure sustainable development. In the absence of suitable policies and mechanisms for sustainable use of groundwater resources, the benefits of watershed programmes can easily be undone with the overexploitation of groundwater (Sreedevi et al., 2006). Supplemental irrigation can play a very important role in reducing the risk of crop failures and in optimizing the productivity in the SAT. Cultivation of water inefficient crops like rice and sugarcane need to be controlled through suitable incentive mechanisms for rainfed irrigated crops and policy should be in place to stop cultivation of high water requiring crops (Wani et al., 2008a).

Convergence and collective action

Convergence of actors and their actions at watershed level is needed to harness the synergies and to maximize the benefits through efficient and sustainable use of natural resources (Wani et al., 2003, 2003b). Enhancing partnerships and institutional innovations through the consortium approach addressing complex issues was the major impetus for harnessing community watershed's potential to reduce household poverty (Wani et al., 2003). Private partners and public partnership provided the means for increased investments and for building institutions as engines for the people-led NRM (Wani et al., 2008b). Incorporating knowledge-based entry point in the approach led to the facilitation of rapport and at the same time enabled the community to take rational decisions for their own development (Dixit et al., 2007).

In 2005, the National Commission on Farmers recommended a holistic integrated watershed management approach, with focus on rainwater harvesting and improving soil health for sustainable development of drought-prone rainfed areas (Government of India, 2005). Recently, Government of

India has established National Rain-fed Areas Authority (NRAA) with the mandate to converge various programmes for integrated development of rainfed agriculture in the country. The common watershed guidelines issued by the Planning Commission have also emphasized the need for convergence and collective action (Government of India, 2008).

Business model

Watersheds should be developed as business model through public-private partnership using principles of market-led diversification using high-value crops, value chain approach and livelihood approach to link small farmers to markets rather than only soil and water conservation approach (Wani et al., 2008, 2008a).

Pilot-scale model community watershed

The ICRISAT-led consortium developed an innovative farmers' participatory consortium model for integrated watershed management (Wani et al., 2002, 2003b, 2003c). The entire process revolves around the 4 E's (empowerment, equity, efficiency and environment), which are addressed by adopting specific strategies prescribed by the 4 C's (consortium, convergence, collective action and capacity building). The consortium strategy brings together institutions from the scientific, non-government, government, and farmers group for knowledge management. Convergence allows integration and negotiation of ideas among actors. Cooperation enjoins all stakeholders to harness the power of collective actions. Capacity building engages in empowerment for sustainability (Wani et al., 2008b).

The important components of the new model, which are distinct from the earlier ones are:

- Collective action by farmers and participation from the beginning through cooperative and collegiate mode in place of contractual mode.
- IWRM and holistic system approach through convergence for improving livelihoods
- A consortium of institutions for technical backstopping.
- Knowledge-based entry point to build rapport with community and enhanced participation.
- Tangible economic benefits to individuals through on-farm interventions enhanced efficiency of natural resources.
- Low-cost and environment-friendly soil and water conservation measures throughout the toposequence for more equitable benefits to large number of farmers.
- Income-generating activities for landless and women through allied sector activities.

Multiple Benefits and Impacts

Through the use of new tools [i.e. remote sensing, geographical information systems and simulation modelling] along with an understanding of the entire food production-utilization system (i.e. food quality and market) and genuine involvement of stakeholders, ICRISAT-led watersheds effected remarkable impacts on SAT resource-poor farm households.

Reducing rural poverty and building resilience in the watershed communities is evident in the transformation of their economies. Crop intensification and diversification with high-value crops is one leading example that allowed households to achieve production of basic staples and surplus for modest incomes. Building on social capital made the huge difference in addressing rural poverty of watershed communities. Today, Adarsha Watershed, Kothapally in A.P, India is a prosperous village on the path of long-term sustainability and has become a beacon for science-led rural development. In 2001, the average village income from agriculture, livestock and non-farming sources was US$ 945 compared with the neighbouring non-watershed village income of US$ 613. During 2002, a drought year, share of agriculture income in a total family income in a non-watershed was reduced to 12%

from 44% in a normal year. In watershed village share of agriculture income in a total family income remained same (36-37%) during normal and a drought year (Fig. 3) indicating the resilience.

Crop Livestock integration has transformed economy of the Lucheba watershed, Guizhou province of southern China through modest injection of capital-allied contributions of labour and finance, to create basic infrastructures like access to roads and drinking water supply. The farming system was intensified from rice and rape seed to tending livestock (pig raising) and growing horticultural crops (fruit trees like *Ziziphus*; vegetables like beans, peas and sweetpotato) and groundnuts. In forage production, wild buckwheat was specifically important as an alley crop as it was a good forage grass for pigs. This holds true in many watersheds of India where the improvement in fodder production has intensified livestock activities like breed improvement (artificial insemination and natural means) and livestock centre/health camp establishment (Wani et al., 2006). In Tad Fa and Wang Chai watersheds in Thailand, there was a 45% increase in farm income within three years. Farmers earned an average net income of US$ 1195 per cropping season (Wani et al., 2006; Sreedevi and Wani 2009).

Increasing crop productivity is a common objective in all the watershed programmes is achieved after the implementation of soil and water conservation practices along with appropriate crop and nutrient management. In the benchmark watersheds of Andhra Pradesh, maize yield increased by 2.5 times (Table 1) and sorghum yield by three folds (Wani et al., 2006). Overall, in the 65 community watersheds in A.P., India implementing the best-bet practices resulted in significant yield advantages in sorghum (35-270%), maize (30-174%), pearl millet (72-242%), groundnut (28-179%), sole pigeonpea (97-204%) and intercropped pigeonpea (40-110%). In Thanh Ha watershed of Vietnam, yields of soybean, groundnut and mung bean increased by three folds to four folds (2.8–3.5 t/ha) as compared with baseline yields (0.5 to 1.0 t/ha). A reduction in nitrogen fertilizer (90–120 kg urea per ha) by 38% increased maize yield by 18% in Vietnam. In Tad Fa watershed of northeastern Thailand, maize yield increased by 27-34% with improved crop management.

Improving water availability in the watersheds through efficient management and harvesting of rainwater and improved groundwater levels (Fig 4). In Lalatora (in M.P, India), treated area registered a groundwater level rise by 7.3 m, at Bundi, Rajasthan, rise was 5.7 m, irrigated area increasing from 207 ha to 343 ha. In Lucheba watershed in China, a drinking water project, which constitutes a water storage tank to harvest springs in hills and pipelines to farm households, was a joint effort of the community and the watershed project. This solved the drinking water problem for 62 households and more than 300 livestock. On the other hand, in Thanh Ha watershed in Vietnam, collective pumping out of well water established efficient water distribution system and enabled farmers' group to earn more income by growing watermelon with reduced drudgery as women had to carry water on the head from a long distance earlier (Wani et al., 2006). Striking results were recorded from supplemental irrigation on crop yields at benchmark watersheds in M.P with increased chickpea yield by 127% over the control yield (0.55 t/ha); and 59% groundnut pod yield over the control yield (0.82 t/ha) with two supplemental irrigations of 40 mm (Pathak et al., 2009).

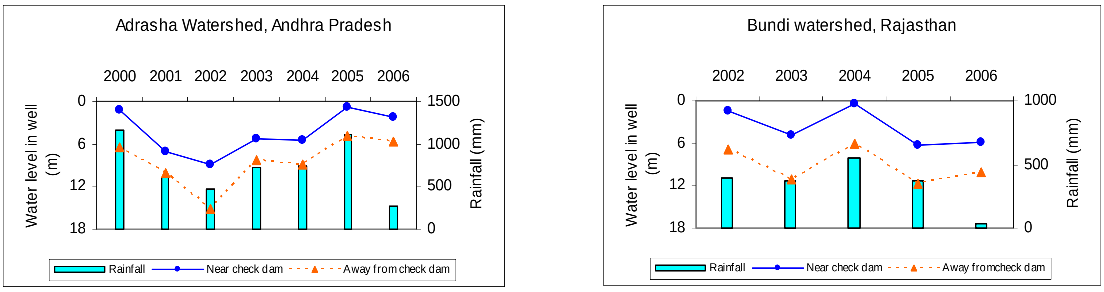


Figure 4. The impact of watershed interventions on groundwater levels at two benchmark sites in India.
(Note: Estimated additional groundwater recharge due to watershed interventions is 6,75,000 m^3/yr in Bundi watershed and 4,27,800 m^3/yr in Adarsha Watershed.) (Wani et al., 2008)

Sustaining development and protecting the environment are the two-pronged achievements of the watersheds. Improved watershed technologies reduced runoff volume, peak runoff rate and soil loss and improved groundwater recharge. This is particularly significant in Tad Fa watershed where interventions such as contour cultivation at mid-slopes, vegetative bunds planted with *Vetiver*, fruit trees grown on steep slopes and relay cropping with rice bean reduced seasonal runoff to less than half (169 mm) and soil loss less than 1/7th (4.21 t/ha) as compared to the conventional system (364 mm runoff and soil loss 31.2 t/ha). This holds true with peak runoff rate where the reduction is approximately one-third (Table 4). Introduction of integrated pest management (IPM) and improved cropping systems decreased the use of pesticides worth US$ 44 to 66 per ha (Ranga Rao et al., 2007). Crop rotation using legumes in Wang Chai watershed (Thailand) substantially reduced nitrogen requirement for rainfed sugarcane. The IPM practices harnessed local knowledge using insect traps of molasses, light traps and tobacco waste, led to extensive vegetable production in Xiaoxingcun (China) and Wang Chai (Thailand) watersheds.

Increased carbon sequestration of 7.4 t/ha in 24 years was observed with improved management of legume-based system in a long-term watershed experiment at ICRISAT (Wani et al. 2003a). The IGNRM options in the watersheds reduced loss of NO_3-N in runoff water (8 vs 14 kg nitrogen per ha). Reduced runoff and erosion reduced risk of downstream flooding and siltation of water bodies that directly improved environmental quality in the watersheds (Pathak et al., 2005).

Table 4. Seasonal rainfall, runoff and soil loss from different benchmark watersheds in India and Thailand

Watersged	Seasonal rainfall (mm)	Runoff (mm)		Soil loss (t ha^{-1})	
		Treated	Untreated	Treated	Untreated
Tad Fa (Khon Kaen, NE Thailand)	1284	169	364	4.21	31.2
Kothapally (Andhra Pradesh, India)	743	44	67	0.82	1.9
Ringnodia (Madhya Pradesh, India)	764	21	66	0.75	2.2
Lalatora (Madhya Pradesh, India)	1046	70	273	0.63	3.2

(Source: Wani et al., 2006)

Scaling-up. The new paradigm for upgrading rainfed agriculture through integrated watershed management can double the productivity in Asia and also reduce poverty without causing further degradation of natural resource base (Wani et al., 2009; Sreedevi and Wani 2009). Successful scaling up of these innovations in Andhra Pradesh, India through APRLP and in other states of India with the support from Sir Dorabji Tata Trust and World Bank (Sujala Project, Karnataka) as well as in Thailand and Vietnam have opened up opportunities to upgrade rainfed agriculture in all these countries as well as in China.

Along with rainwater harvesting and agumentation, water demand management through enhanced water use efficiency (both rain and groundwater) by adopting a holistic approach has benefited the farmers. Farmers obtained 13 to 230% increase in maize yields with an average increase of 72% over the base yield of 2980 kg/ha; the increase in castor yields was 21 to 70% with an average increase of 60% over the base yield of 470 kg/ha. Similarly, groundnut yield increased by 28% over the base yield of 1430 kg/ha. The issues of equity for all in the watershed call for innovative approaches; institution and policy guidelines for equitable use of water resources are needed. Sustainable use of common property resources in the watershed also need to be addressed. Building on micro-enterprises enhanced the benefits for women and vulnerable groups in the society. Knowledge management and sharing is an important aspect in management of natural resources for sustainable development through ICT with the large number of small and marginal farmers (Sreedevi and Wani 2009).

Conclusion

In conclusion, the rain-fed areas which are hot-spots of poverty, water scarcity and prone to severe land degradation are also likely to be affected severely due to the impacts of climate change. Vast untapped potential of rain-fed areas if unlocked by adopting integrated community watershed approach can increase food production and achieve food security. However, to bridge the yield gaps new paradigm involving consortium, collective action, convergence of actors and programs and capacity building of stakeholders is needed. It calls for change in the mindset and the way we link researchers – development workers and farmers and markets to build resilience.

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References

Dixit, S., Wani, S.P., Rego, T.J. and G. Pardhasaradhi (2007) Knowledge-based Entry Point and Innovative Up-scaling Strategy for Watershed Development Projects. Indian Journal of Dryland Agriculture and Development 22(1):22-31.

Government of India. (2005) Serving Farmers and Saving Farming – 2006: Year of Agricultural Renewal. Third Report. December 2005. National Commission on Farmers, Ministry of Agriculture, Government of India, New Delhi, India. 305 pp.

Government of India. (2008) Common guidelines for watershed development projects. Ministry of Agriculture, Government of India, 57 pp.

IIASA. (2002) Climate change and agricultural vulnerability. Special report for the UN World Summit on sustainable Development, Johhanesburg, 2002, (160 pp). (http://www.iiasa.ac.at/Research/LUC/JB-Report.pdf).

IPCC. (2007) Climate change - impacts, Adaptation and vulnerability Technical summary of Working group II. to Fourth Assessment Report Inter-governmental Panel on Climate Change. Parry, M.L., Canziani, O.F., Paultikof, J.P., van der Linden, P.J. and Hanon, C.E. (Eds.), Cambridge University press, Cambridge, U.K. pp. 23-78.

Farrington, J. and C. Lobo (1997) Scaling up participatory watershed development in India: lessons from the Indo-German Watershed Development Program. Natural Resource Perspective, Number 17, February 1997. London, UK:ODI

Joshi, P.K., Jha, A.K., Wani, S.P., Joshi, Laxmi and R.L. Shiyani (2005) Meta-analysis to assess impact of watershed program and people's participation. Comprehensive assessment Research Report 8, Colombo, Sri Lanka: Comprehensive Assessment Secretariat. IWMI, Sri Lanka pp. 18.

Joshi, P.K., Jha, A.K., Wani, S.P. and T.K. Sreedevi (2009) Scaling-out Community Watershed Management for Multiple Benefits in Rainfed Areas. In: Rain-fed agriculture: Unlocking the Potential. (Wani SP, John Rockstrom and Theib Oweis Eds.). Comprehensive Assessment of Water Management in Agriculture Series, CAB International, Wallingford, UK, pp.258-275.

Kerr, J., Pangare, G. and V. Pangare (2002) Watershed development project in India: An evaluation. Research Report no. 127. Environment and Policy Production Technology Division, International Food Policy Research Institute, Washington, DC, USA. 102 p.

Molden, D., Karen Frenken, Randolph Barker, Charlotte de Fraiture, bancy Mati, mark Svendsen, Claudia Sadoff, and Max Finlayson, it is Molden in the text, please check! (2007) Trends in water and agricultural development In: Moden, D. (ed.) 'Water for Food: Water for Life- A Comprehensive Assessment of Water Management in Agriculture' International Water Management Institute (IWMI), Colombo, Srilanka, pp. 57-89.

Mwale, F. (2003) Drought impact on maize production in Malawi. Unesco-IHE Report. Delft, The Netherlands.

Oweis, T. and A. Hachum (2001) Reducing peak supplemental irrigation demand by extending sowing dates. Agricultural Water Management 50,109-123.

Pathak, P., Sahrawat, K.L., Rego, T.J. and S.P. Wani (2005) Measurable biophysical indicators for impact assessment: changes in soil quality. In: Shiferaw, B., Freeman, H.A. and Swinton, S.M. (eds) Natural Resource Management in Agriculture: Methods for assessing Economic and Environmental Impacts. CAB International, Wallingford, UK, pp 53-74.

Pathak, P., Sahrawat, K.L., Wani, S.P., Sachan, R.C. and R. Sudi (2009) Opportunities for water harvesting and supplemental irrigation for improving rain-fed agriculture in semi-arid areas. In: Rain-fed agriculture:

Unlocking the Potential. Wani SP, Rockström J and Oweis T (eds) Comprehensive Assessment of Water Management in Agriculture Series, CAB International, Wallingford, UK, pp. 197-221.

Ranga Rao, G.V., Rupela, O.P., Wani, S.P., Rahman, S.J., Jyothsna, J.S., Rameshwar Rao, V. and P. Humayun (2007) Bio-intensive pest management reduces pesticide use in India. Journal of Integrated Pest Management. Pesticides News 76. June 2007. 16-17

Rego, T.J., Wani, S.P., Sahrawat, K.L. and G. Pardhasardhy (2005) Macro-benefits from boron, zinc, and sulphur application in Indian SAT: A step for Grey to Green Revolution in Agriculture. GTAES, Report no. 16. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, A.P, India, 24 pp.

Rego, T.J., Sahrawat, K.L., Wani, S.P. and G. Pardhasaradhi (2007) Widespread Deficiencies of Sulfur, Boron and Zinc in Indian Semi-Arid Tropical Soils: On-Farm Crop Responses. Journal of Plant Nutrition. 30: 1569-1583.

Rockström, J. and M. Falkenmark (2000) Semiarid crop production from a hydrological perspective: Gap between potential and actual yields. Critical Reviews in Plant Science 19(4), 319-346.

Rockström, J. (2003) Water for food and nature in the tropics: vapour shift in rain-fed agriculture. Invited paper to the Special issue 2003 of Royal Society Transactions B Biology, Theme Water Cycle as Life Support Provider, 358(1440),1997-2009.

Rockström, J., Nuhu Hatibu, Theib Oweis and S.P. Wani (2007) Managing water in rain-fed agriculture. In: Molden, D., (ed.) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture, Earthscan, London, UK and International Water Management Institute (IWMI), Colombo, Srilanka, pp. 315-348.

Rosegrant, M., Ximing, C., Cline, S. and N. Nakagawa (2002) The role of rain-fed agriculture in the future of global food production. EPTD Discussion Paper No. 90, Environment and Production Technology Division, IFPRI, Washington DC, USA, 105 pp. (http://www.ifpri.org/divs/eptd/dp/papers/eptdp90.pdf)

Ryan, J.G. and D.C. Spencer (2001) Challenges and Opportunities Shaping the Future of the Semi-Arid Tropics and their Implications. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, 83 pp.

Sahrawat, K.L., Wani, S.P., Rego, T.J., Pardhasaradhi, G. and K.V.S. Murthy (2007) Widespread deficiencies of sulphur, boron and zinc in dryland soils of the Indian semi-arid tropics. Current Science, Vol.93, No.10. 1-6

Sanchez, P., Swaminathan, M.S., Dobie, P. and N. Yuksel (2005) Halving Hunger: It Can be Done. Summary version of the report of the Task Force on Hunger, New York, USA. The Earth Institute at Columbia University.

Shambu Prasad, C., Hall, A.J. and S.P. Wani. it is Shambhu Prasad in the text, check! (2005) Institutional History of Watershed Research: The Evolution of ICRISAT's Work on Natural Resources in India. GTAES, Report No. 12, Patancheru, A.P, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp.

Shiferaw, B., Cynthia Bantilan and S.P. Wani (2008) Rethinking policy and institutional imperatives for integrated watershed management: Lessons and experiences from semi-arid India. Journal of Food, Agriculture & Environment Vo. 6(2). 370-377

Singh, P., Aggarwal, P.K., Bhatia, V.S., Murty, M.V.R., Pala, M., Oweis, T., Benli, B., Rao, K.P.C. and S.P. Wani (2009) Yield gap analysis: modeling of achievable yields at farm level in Rainfed Agriculture: Unlocking the Potential (ed. Wani, S.P., Rockstorm J. and Oweis, T.). CAB International, UK, pp. 81-123.

SIWI. (2001) Water harvesting for upgrading of rain-fed agriculture. Policy analysis and research needs. SIWI Report II. Stockholm International Water Institute (SIWI), Stockholm, Sweden. 104 pp.

Sreedevi, T.K. and S.P. Wani (2009) Integrated farm management practices and up-scaling the impact for increased productivity of rainfed systems. In: Rain-fed agriculture: Unlocking the Potential. Wani SP, Rockström J and Oweis T (eds) CA of Water Management in Agriculture Series, CAB International, Wallingford, UK, pp. 222-257

Sreedevi, T.K., Wani, S.P., Sudi, R., Mahesh S. Patel, Jayesh Talati, Singh, S.N. and Tushar Shah (2006) On-site and off-site impact of watershed development: A case study of Rajasamadhiyala, Gujarat, India. GTAES, Report No.20. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P, India, 48 pp.

Wani, S.P., Pathak, P., Tam, H.M., Ramakrishna, A., Singh, P. and T.K. Sreedevi (2002) Integrated Watershed Management for Minimizing Land degradation and Sustaining Productivity in Asia, in Integrated land management in the dry areas (Zafar Adeel ed), Proceedings of Joint UNU-CAS International Workshop Beijing, China, Jingu-mae 5-53-70, Shibuya-ku, Tokyo-1508925, united nations University. Pp 207-230.

Wani, S.P., Maglinao AR., Ramakrishna, A. and T.J. Rego (eds) (2003) Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia. Proceedings of the ADB-ICRISAT-IWMI Annual Project Review and Planning Meeting, Hanoi, Vietnam, 10-14 December 2001. 268 p

Wani, S.P., Pathak, P., Jangawad, L.S., Eswaran, H. and P. Singh (2003a) Improved management of Vertisols in the SAT for increased productivity and soil carbon sequestration. Soil Use and Management, 19, 217-222.

Wani, S.P., Pathak, P, Sreedevi, T.K., Singh, H.P. and P. Singh (2003b) Efficient management of rainwater for increased crop productivity and groundwater recharge in Asia. In: Kijne, J.W., Barker, R. and Molden, D. (eds) Water Productivity in Agriculture: Limits and Opportunities for Improvement. CAB International, Wallingford, UK; International Water Management Institute (IWMI), Colombo, Sri Lanka, pp. 199-215

Wani, S.P., Singh, H.P., Sreedevi, T.K., Pathak, P., Rego, T.J., Shiferaw, B. and S.R. Iyer (2003c) Farmer-participatory integrated watershed management: Adarsha Watershed, Kothapally India. An Innovative and up-scalable approach. A Case Study. In: Harwood, R.R. and Kassam, A.H. (ed) Research Towards Integrated Natural Resources Management: Examples of Research Problems, Approaches and Partnerships in Action in the CGIAR. Interim Science Council, CGIAR, Washington, DC, USA, pp. 123-147.

Wani, S.P., Ramakrishna, Y.S., Sreedevi, T.K., Long, T.D., Thawilkal Wangkahart, Shiferaw, B., Pathak, P. and A.V.R. Kesava Rao (2006) Issues, concepts, approaches and practices in integrated watershed management: Experience and lessons from Asia. In: Integrated Management of Watersheds for Agricultural Diversification and Sustainable Livelihoods in Eastern and Central Africa; Lessons and Experiences from Semi-Arid South Asia. Proceedings of the International Workshop held at ICRISAT, Nairobi, 6–7 December 2004. pp. 17-36.

Wani, S.P., Joshi, P.K., Ramakrishna, Y.S., Sreedevi, T.K., Piara Singh and P. Pathak (2008) A New Paradigm in Watershed Management: A Must for Development of Rain-fed Areas for Inclusive Growth. Conservation Farming: Enhancing Productivity and Profitability of Rainfed Areas, Eds: Anand Swarup, Suraj Bhan and JS Bali. 2008. Soil Conservation Society of India, New Delhi. 163-178

Wani, S.P., Joshi, P.K., Raju, K.V., Sreedevi, T.K., Mike Wilson, Amita Shah, Diwakar, P.G., Palanisami, K., Marimuthu, S., Ramakrishna, Y.S, Meenakshi Sundaram, S.S. and Marcella D'souza (2008a) Community Watershed as Growth Engine for Development of Dryland areas - Executive Summary. A Comprehensive Assessment of Watershed Programmes in India. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, A.P, India, 32 p.

Wani, S.P., Sreedevi, T.K., Vamsidhar Reddy, T.S., Venkateshvarlu, B. and C. Shambhu Prasad (2008b) Community Watersheds for Improved Livelihoods through Consortium Approach in Drought Prone Rainfed Areas. Journal of Hydrological Research and Development, Vol. 23, 2008. pp 55-77.

Wani, S.P., Rockström, J. and T. Oweis (Eds) (2009) Rain-fed agriculture: Unlocking the Potential. Comprehensive Assessment of Water Management in Agriculture Series, CAB International, Wallingford, UK, pp. 1-325.