Proceedings of the International Conference on

Water, Environment, Energy and Society (WEES-2009)

January 12-16, 2009, New Delhi, India

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VOLUME–IV

Water Resources Planning and Management

Organized by

National Institute of Hydrology, Roorkee
Ministry of Water Resources, Government of India
New Delhi–110 001

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International Conference "Water, Environment, Energy and Society" (WEES–2009)
New Delhi, 12–16 January 2009

Community Watersheds for Sustainable Development and Improved Livelihoods in Dryland Areas of Asia

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ABSTRACT: Rainfed areas constitute globally 80% of cultivated area and will continue to contribute significantly for global food security. The crop yields in the farmers' fields in rain-fed areas of developing countries are lower by two to five folds than the achievable yields. Rainwater use efficiency is generally very low. In order to achieve food security and reduce poverty, rainfed agriculture needs to be upgraded by adopting community watershed approach for sustainable development. Watersheds are not merely hydrological units but, are dynamic systems comprising human beings and animals; and link upstream and downstream areas and are prone to a number of externalities. India has adopted watershed approach over time for development of rainfed areas and substantial investments to the tune of US$ 6 billion have been made till 2006. However, the performance of the watershed program is not to the desired level as 66% of the programs are performing below average. Recent comprehensive assessment of watershed programs in India revealed that community watersheds not only for soil and water conservation measure but also need to be holistic and inclusive addressing equity and gender concerns, productivity enhancement, employment generation, income enhancement and also building resilience of the community and the natural re sources to meet the challenges of the future including climate change. This paper describes the importance of rainfed agriculture and shortcomings in the current watershed programme and new paradigm of community watershed development along with insights by learnings from large number of watershed programs in Asia.

INTRODUCTION

Rainfed areas in the developing world are the hot spots of poverty, malnutrition, water scarcity, severe land degradation. Farmer's 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). Most of 852 million hungry and malnourished people in the world are in Asia, particularly in India (221 million) and in China (142 million). In Asia, 75% of the poor are in rural areas those depend on agriculture for their livelihood. About half of the hungry live in smallholder farming households, while two-tenths are land-less (Sanchez *et al.*, 2005). Within developing Semi Arid Tropics (SAT) poverty is concentrated more in rain-fed areas (Ryan and Spencer, 2001). Rain-fed agriculture becomes important not only because of large areas but also from social and equity concerns for improving the livelihoods of large number of people to meet the Millennium Development Goal (MDG) of reducing the number of poor to half by 2015 (Wani *et al.*, 2004). Globally rain-fed agriculture is very important and will continue to play an important role to achieve food security (Rockstorm *et al.*, 2007) 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). Most food for poor communities in developing countries is produced in rain-fed areas for e.g. in Sub-Saharan Africa (SSA) where more than 95% of the farmed land is rain-fed, while the corresponding figure for Latin America is nearly 90%, for South Asia about 60%, for East Asia 65% and for Near East and North Africa 75%. In India, 60 per cent of 142 million ha arable land is rain-fed.

INSIGHTS IN RAIN-FED AREAS

An insight into the rain-fed regions show a grim picture of water-scarcity, fragile environments, drought and land degradation due to soil erosion by wind and water, low rainwater use efficiency (35–45%), high population pressure, poverty, low investments in water use efficiency measures, poor infrastructure and inappropriate policies (Wani *et al.*, 2003, Rockstrom *et al.*, 2007). Drought and land degradation are interlinked with a cause and effect relationship and both in turn are the causes of poverty. This unholy nexus between drought, poverty, and land degradation has to be broken if we have to meet the MDG of halving the number of food insecure poor by 2015. Land degradation through accelerated erosion due to agriculture is irreversible. The torrential character of the seasonal rainfall creates high risk for the cultivated lands. For example, on 23rd June, 2007, Kurnool in Andhra Pradesh, India received 420 mm rainfall in a day against 77 mm monthly average. Thus, erosion leaves behind an impoverished soil on one hand, and siltation of reservoirs and tanks on the other. In addition imbalanced use of nutrients in agriculture by the farmers results in mining of soil nutrients. For example in India large number of farmers participatory watershed management trials in more than 300 villages demonstrated that in SAT current subsistence agricultural systems have depleted soils not only macro-nutrients but also micro-nutrients namely, zinc and boron and secondary nutrients such as sulphur, beyond the critical limits. Widespread (80 to 100%) deficiencies of micro and secondary nutrients were observed in farmers' fields in different states of India (Table 1) (Rego *et al.*, 2007 and Sahrawat *et al.*, 2007).

POTENTIAL OF RAIN-FED AGRICULTURE

In tropical regions, particularly in the sub-humid and humid zones, agricultural yields in commercial rainfed 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, Rockstrom *et al.*, 2007). Rosegrant *et al.*, 2002 observed that rain-fed grain yields in developing countries averaged around 1.5 t ha^{-1} as compared to 3.5 t ha^{-1} for irrigated yields and increase in production from rain-fed agriculture has mainly originated from land expansion. Similarly, Sreedevi *et al.*, 2006 noted that though rainwater harvesting prosperity was much evident in Rajasamadhiyala watershed in India which was largely due to increased cropping intensity with increased water availability but the crop yields were increased marginally by 20% over the district crop average yield. Evidence from long-term experiments at ICRISAT, Patancheru, India, since 1976, demonstrated the virtuous cycle of 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 yr) compared to 1.1 t ha^{-1} per yr, average yield of sole sorghum in the traditional (farmers') post-rainy system where crops are grown on stored soil moisture (Figure 1) with 5 t ha^{-1} farm yard manure once in two years. The annual gain in grain yield in the improved system was 82 kg ha^{-1} per year compared to 23 kg ha^{-1} per year in the traditional system. The large yield gap between attainable yield and farmers' practice as well as between the attainable yield of 5.1 t ha^{-1} and potential yield of 7 t ha^{-1} showed that a large potential of rain-fed agriculture remained to be tapped. Moreover, the improved management system is still gaining in productivity as well as improved soil quality (physical, chemical, and biological parameters) along with increased carbon sequestration of 330 kg C ha^{-1} per year (Wani *et al.*, 2003a). Yield gap analyses, undertaken by the Comprehensive Assessment (CA), for major rainfed crops in semi-arid regions in Asia

Table 1: Farmers' Fields Deficient in Soil Nutrients in Different States of India

State	*No. of Farmers' Fields*	*Organic Carbon*	*Available P*	*Available K*	*Available S*	*Available B*	*Available Zn*
Andhra Pradesh	1927	84	39	12	87	88	81
Karnataka	1260	58	49	18	85	76	72
Madhya Pradesh	73	9	86	1	96	65	93
Rajasthan	179	22	40	9	64	43	24
Gujarat	82	12	60	10	46	100	82
Tamil Nadu	119	57	51	24	71	89	61
Kerala	28	11	21	7	96	100	18

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 rainfed crops grown in Asia and Africa (Rockström *et al.*, 2007).

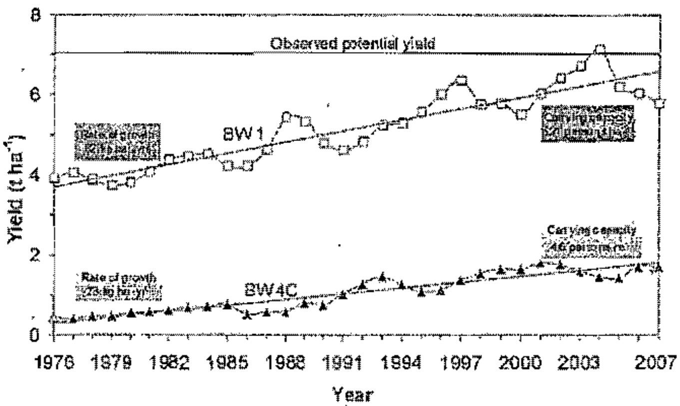

Fig. 1: Three-year moving average of crop yields in improved and traditional management systems during 1976–2007 at ICRISAT, Patancheru, India

Watersheds as Growth Engine for Development of Rain-fed Areas

Integrated Watershed Management (IWM) has been promoted as a suitable strategy for improving productivity and sustainable intensification of agriculture in rain-fed drought-prone regions. India has one of the largest micro-watershed development programs in the world. The watershed development program is continuously evolving in the country through new guidelines, policies, institutions, and expanding the scope of the watershed programs (Wani *et al.*, 2008, 2008a and Government of India 2008). Current watershed programs are addressing the issues of not only soil and water conservation but also focusing towards holistic and very much inclusive encompassing equity, gender, productivity enhancement, employment generation, income enhancement, and most importantly to build the resilience of the community and the natural resources to meet the challenges of future including climate change (Wani *et al.*, 2008a). The hydrological approach helps identify the appropriate technical interventions on the supply side while the village or community-based planning and implementation is fundamental for creating institutions for community empowerment and sustainability on the demand side (Shiferaw *et al.*, 2008). Community-based IWM interventions create synergies between targeted technologies, policies and institutions that improve productivity, resource use sustainability and market access for the resource users (Wani *et al.*, 2003c).

Watershed is a spatial unit, the water flowing through the watershed interconnect up-stream and down stream areas and provide life support to rural people making people and animals an integral part of watersheds. Activities of people/animals affect the health and sustainability of watersheds and *vice versa*. This creates interdependence between resources as well as resource users over time and space. By definition, watersheds require a hydrologically defined spatial scale for technological interventions to succeed. The actual size of this unit depends on topographic and agro-climatic conditions and may range from a few hectares (ha) to over thousands of ha depending on the objectives of the interventions. This implies that effectiveness of watershed interventions will depend on the ability to treat the entire hydrological landscape, not just a portion of it. In most parts of the world watersheds are described as large hydrological unit at basin level. However, in India based on the important role of the community in watershed development and to avoid conflicts amongst the villages covered by a large watershed, micro-watersheds of 500 to 1000 ha are used as unit to be developed by adopting community participatory approach. Till 2006 up to 10th five year plan, about US $ 6 billions have been invested by Government of India and other donor agencies for treating 38 million ha in the country (Table 2). Appreciating this fact, the new generation of watershed development programmes is implemented with a larger aim to address issues of food security, equity, poverty, severe land degradation and water scarcity in dry land areas. Hence, in the new approach, Watershed, a land unit to manage water resources has been adopted as a planning unit to manage natural resources of an area. Realizing the fact that in the absence of them, sustainable NRM would be illusive. These highlights need to improve livelihoods of local communities. Due to these considerations watershed programmes have been looking beyond soil and water conservation into a range of activities from productivity enhancement through interventions in agriculture, horticulture, animal husbandry to community organization and gender equity. This holistic approach requires optimal contribution from different discipline to create a demand for multi-stakeholder situation in watershed development programmes.

Although, watershed development approach is embraced as a policy for development of drought prone regions in the country, however, number of evaluations showed that all were not gone well with

Table 2: Degraded Land under Various Watershed Development Programmes

(Area in lakhs ha and Expenditure in Rs. Crores)

S. No.	Ministry/Scheme	Year of Start	Progress up to 10th Five Year Plan (up to March 2006)		Projection for 10th Five Year Plan	
			Area Treated	Amount Expenditure	Area Target	Financial Requirement
A. Ministry of Agriculture (Department of Agriculture and Cooperation)						
1.	NWDPRA	1990–91	85.59	2671.56	40.0	3000.0
2.	RVP & FPR	1962 & 81	62.57	1908.43	20.0	2400.0
3.	WDPSCA	1974–75	3.52	255.58	2.0	240.0
4.	RAS	1985–86	6.87	105.94	5.0	287.0
5.	WDF	1999–2000	0.39	2101.5	4.0	300.0
6.	EAPs		28.0	4980.0	5.0	750.0
7.	New schemes for problem soils				24.0	2950.0
	Sub-Total		186.94	12023.01	100.0	9927.0
B. Ministry of Rural Development (Department of land Resources)						
8.	DPAP	1973–74	65.74	5060.5	40.0	3000.0
9.	DDP	1977–78	35.31	1960.75	30.0	2250.0
10.	IWDP	1988–89	84.54	2228.41	70.0	5250.0
11.	EAPs		3.6	212.67		
	Sub-Total		189.19	9462.33	140.0	10500.0
C. Ministry of Environment and Forestry						
12.	NAEP	1989–90	8.77	852.89		
D. Planning Commission						
13.	HADP	From V plan		4908.26		
14.	WGDP	From V plan		1426.65	10.0	750.0
	Sub-Total			6334.91	10.0	750.0
E. Public-Private- Partnership (PPP)					30.0	2250.0
	Total		384.9	28673.14 (= US$ 644.34)	280.0	23427.0 (= US$ 526.45)

Note: Currency conversion @ 44.50 INR = 1 US$; one crore = ten million.

Abbreviations: NWDPRA - National Watershed Development project for Rainfed Areas; RVP & FPR - River Valley Project & Flood Prone River; WDPSCA - Watershed Development Project for Shifting cultivation Areas; RAS - Reclamation of Alkali Soil; WDF - Watershed Development Fund; EAP - External Aided Projects; DPAP - Drought Prone Area Programme; DDP - Desert Development Programme; IWDP - Integrated Wasteland Development Project; NAEP - National Afforestation and Eco-Development project; HADP - Hill Area Development Programme; WGDP - Western Ghats Development Programme.

the watershed programmes (Kerr *et al.*, 2002, Farrington and Lobo, 1997, Joshi *et al.*, 2005, Wani *et al.*, 2002, 2003). Evaluation of first generation on-farm watershed development research ICRISAT team reported that in spite of clear demonstration of economic benefits, farmers reverted back to their earlier soil and water management options and only few components of the improved soil, water and nutrient management options were adopted and continued. Subsequent meta-analysis of 311 watersheds case studies from different agro-eco regions in India revealed that watershed programmes were economically viable and productive with a benefit–cost ratio of 2.14 and the internal rate of return of 22%. The watersheds also benefited farmers through enhanced irrigated areas by 33.5%, increased cropping intensity by 63%, reducing soil loss to 0.8 t ha^{-1} and runoff to 13%, and improved groundwater availability (Joshi *et al.*, 2005). However, about 65% of the case studies showed below average performance. (Figure 1). Recently, ICRISAT-led consortium undertook comprehensive assessment of watershed programs in India. The meta analysis of

636 watershed case studies revalidated the results of earlier meta analysis study (Wani *et al.*, 2008). The comprehensive assessment of watershed programs has described watershed development approach as growth engine of sustainable development in dryland areas and have recommended changes in watershed guidelines, policies and approach. The CA has recommended watersheds to be developed as business model through public private partnership mode and convergence of actors and programs with full community participation for addressing the issues of 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).

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 business as usual in global agriculture would not be able to meet the goal of food security and reducing the poverty. If situation continued it will lead to crises in many parts of the world (Molden, 2007). However, the world's available land and water resources can satisfy future demands by taking the following steps:

- Upgrading rain-fed agriculture by investing more in rain-fed agriculture to enhance agricultural productivity (rain-fed scenario).
- Discard the artificial divide between rain-fed and irrigated agriculture and adopt integrated water resource management approach for enhancing resource efficiency and agricultural productivity.
- Investing in irrigation for expanding irrigation where scope exists and improving efficiency of the existing irrigation systems (irrigation scenario).
- Conducting agricultural trade within and between countries (trade scenario).
- Reducing gross food demand by influencing diets and reducing post-harvest losses, including industrial and household waste.

To upgrade 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, Rockstrom *et al.*, 2007 and Wani *et al.*, 2008). We need to have a holistic approach based on converging all the necessary aspects of natural resource conservation, their efficient use, production functions and income enhancement avenues through value chain and enabling policies and much needed investments in rainfed areas.

Holistic Watershed Approach through Integrated Genetic and Natural Resource Management (IGNRM)

Traditionally, crop improvement and NRM were seen as distinct but complementary disciplines. ICRISAT has deliberately blurred these boundaries to create the new paradigm of IGNRM (Twomlow *et al.*, 2006) to solve farming problem. Improved varieties and improved resource management are two sides of the same coin. The systems approach looks at various components of the rural economy-traditional food grains, new potential cash crops, livestock and fodder production, as well as socioeconomic factors such as alternative sources of employment and income. Crucially the IGNRM approach is participatory, with farmers closely involved in technology development, testing and dissemination.

ICRISAT's studies in Africa and Asia have identified several key constraints to more widespread technology adoption (Ryan and Spencer, 2001). Other institutes have independently reached similar conclusions for other agroecosystems. So there is general agreement on the key challenges before us. These are:

- Lack of a market-oriented smallholder production system where research is market-led, demand-driven and follows the commodity chain approach to address limiting constraints along the value chain.
- Poor research-extension-farmer linkages, which limit transfer and adoption of technology.
- Need for policies and strategies on soil, water and biodiversity to offset the high rate of natural resource degradation.
- Need to focus research on soil fertility improvement, soil and water management, development of irrigation, promotion of integrated livestock-tree-crop systems and development of drought mitigation strategies.
- Need to strengthen capacities of institutions and farmers' organizations to support input and output marketing and agricultural production systems.
- Poor information flow and lack of communication on rural development issues.
- Need to integrate a gender perspective in agricultural research and training as seen in ICRISAT's work on community watershed, VASAT and village level studies.

In much of agricultural research, the multi-disciplinary team approach has often run into difficulties in achieving impact because of the perceived disciplinary hierarchy. The IGNRM approach in Community Watershed Consortium pursues integration of the knowledge and products of the various research disciplines into useful extensions messages for development workers that can sustain increased yields for a range of climatic and edaphic conditions. In Asia, the integrated community watershed management approach that aims at to promote income-generating and sustainable crop and livestock production options as an important component of improved management of watershed landscapes is a live example of how IGNRM led to significant benefits in a poor area (Tables 4, 5 and Figure 2). This holistic participatory approach is transforming the lives of poor small and marginal farmers into prosperity in the dryland areas of Asia (Wani *et al.*, 2006a).

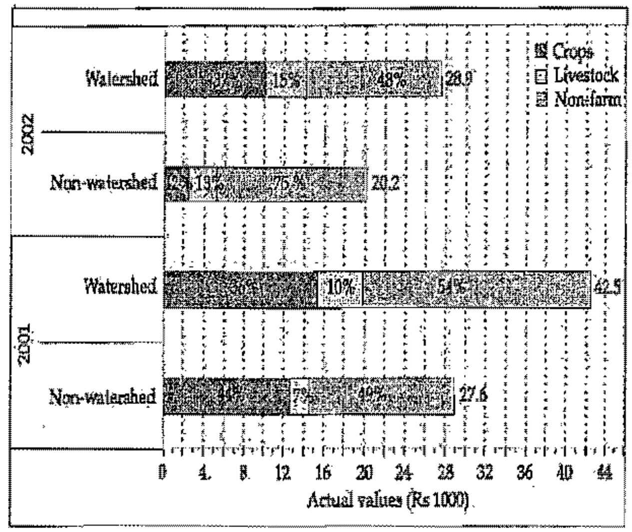

Fig. 2: Effect of integrated watershed management on flow of household net income
(*Source:* ICRISAT Data–Adarsha Watershed, Andhra Pradesh, India)

Table 3: Benefits of Watersheds—Summary of Meta-analysis

Indicator	*Particulars*	*Unit*	*No. of Studies*	*Mean*	*Mode*	*Median*	*Min*	*Max*	*t-value*
Efficiency	B/C ratio	Ratio	128	2.14	1.70	1.81	0.82	7.06	21.25
	IRR	Per cent	40	22.04	19.00	16.90	1.68	94.00	6.54
Equity	Employment	Person days/ha/yr	39	181.50	75.00	127.00	11.00	900.00	6.74
Sustainability	Irrigated area	Per cent	97	33.56	52.00	26.00	1.37	156.03	11.77
	Cropping intensity	Per cent	115	63.51	80.00	41.00	10.00	200.00	12.65
	Rate of runoff	Per cent	36	–13.00	–33.00	–11.00	–1.30	–50.00	6.78
	Soil loss	Tons/ha/yr	51	–0.82	–0.91	–0.88	–0.11	–0.99	39.29

Table 4: Effect of Integrated Water Management Interventions on Runoff and Soil Erosion from Adarsha Watershed, Andhra Pradesh, India

Year	*Rainfall (mm)*	*Runoff (mm)*		*Peak Runoff Rate (m^3/s/ha)*		*Soil Loss (t/ha)*	
		Untreated	*Treated*	*Untreated*	*Treated*	*Untreated*	*Treated*
1999	584	16	NI(a)	0.013	NI(a)	NI(a)	NI(a)
2000	1161	118	65	0.235	0.230	4.17	1.46
2001	612	31	22	0.022	0.027	1.48	0.51
2002	464	13	Nil	0.011	Nil	0.18	Nil
2003	689	76	44	0.057	0.018	3.20	1.10
2004	667	126	39	0.072	0.014	3.53	0.53
2005	899	107	66	0.016	0.014	2.82	1.20
2006	715	110	75	0.003	0.001	2.47	1.56
Mean	724	75 (10.4%)	44 (6.1%)	0.054	0.051	2.55	1.06

(a) Not installed.
Source: Sreedevi *et al.* (2007).

Table 5: Crop Yields in Adarsha Watershed Kothapally during 1999–2007

Crop	*1998 Base-Line Yield*	*Yield (Kg ha^{-1})*									
		1999–2000	*2000–2001*	*2001–2002*	*2002–2003*	*2003–2004*	*2004–2005*	*2005–2006*	*2006–2007*	*Average yields*	*SE^{+}*
Sole maize	1500	3250	3750	3300	3480	3920	3420	3920	3635	3640	283.3
Improved Inter cropped maize	–	2700	2790	2800	3083	3129	2950	3360	3180	3030	263.0
Traditioal inter-cropped maize	–	700	1600	1600	1800	1950	2025	2275	2150	1785	115.6
Improved inter-cropped pigeonpea	–	640	940	800	720	950	680	925	970	860	120.3
Traditional inter-cropped pigeonpea	190	200	180	–	–	–	–	–	–	190	–
Improved Sole Sorghum	–	3050	3170	2600	2425	2290	2325	2250	2085	2530	164.0
Traditional Sole Sorghum	1070	1070	1010	940	910	952	1025	1083	995	1000	120.7
Intercroped Sorghum	–	1770	1940	2200	–	2110	1980	1960	1850	1970	206.0

ICRISAT and the national agricultural research systems (NARS) in Asia have developed an innovative and upscalable consortium model for managing watersheds holistically. In this approach, rainwater management is used as an entry point activity starting with *in-situ* conservation of rainwater, and convert the benefits of stored rainwater into increased productivity by using improved crops, cultivars, suitable nutrient and pest management practices and land and water management practices (Table 5). The households incomes and overall productivity had more than doubled throughout selected benchmark sites in Asia (Figure 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 crop income in the watershed villages during the drought year 2002 was noteworthy (Figure 2). While the share of crops in household income declined from 44% to 12% in the non-project villages. The crop income remained largely unchanged from 36% to 37% in the watershed village. The loss in household income in the non-project villages was largely compensated by migration and non-farm income.

Soil Health: An Important Driver for Enhancing Water Use Efficiency

Soil health is severely affected due to land degradation that needs urgent attention. ICRISAT's on-farm diagnostic work in different community watersheds in different states of India as well as in China, Vietnam and Thailand showed severe mining of soils for essential plant nutrients resulting in widespread (80–100%) deficiencies, micronutrients like zinc, boron and secondary nutrients such as sulphur (Table 1) along with N&P. In addition, soil organic matter is very much in short supply particularly in tropical countries. Management practices that augment soil organic matter and maintain a threshold level are needed. Farm bunds could productively be used for growing nitrogen-fixing shrubs and trees to generate nitrogen-rich loppings. For example, growing *Gliricidia sepium* at close 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 valuable source of plant nutrients and organic matter through vermicomposting (Wani *et al.*, 2005). Strategic long-term catchment research at ICRISAT has shown that legume-based systems particularly with pigeonpea could sequester 330 kg carbon up to 150 cm depth in Vertisols at Patancheru, India under rainfed conditions (Wani *et al.*, 2003a).

A substantial increase in crop yields was experienced after micronutrient amendments, and a further increase by 70 to 120% when both micronutrients and adequate nitrogen and phosphorus were applied, for a number of rainfed crops (maize, sorghum, mung bean, pigeonpea, chickpea, castor and groundnut) (Rego *et al.*, 2005 and 2007). In terms of net economic returns, rainwater productivity was substantially higher by 1.50 to 1.75 times (Rego *et al.*, 2005).

WATER RESOURCES MANAGEMENT

For enhancing rainwater use efficiency in rainfed agriculture, the management of water alone cannot result in enhanced water productivity as the crop yields in these areas are limited by additional factors than water limitation. ICRISAT's experience in rainfed areas has clearly demonstrated that more than water quantity per se management of water resources is the limitation in the SAT regions (Wani *et al.*, 2006a). 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).

As indicated by Agarwal (2000), India would not have to suffer from droughts, if local water balances were managed properly. Even during drought years, watershed development efforts of improving rainfall management have benefited Indian farmers (Wani *et al.*, 2006b).

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). In 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 resulted 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. These indicate a large scope of opportunity. Low agricultural yields in rainfed 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. The farmers' reality is influenced by other constraints such as labour shortage, insecure land ownership, capital constraints and limitation in human capacities.

Shifting Non-productive Evaporation to Productive Transpiration

Rainwater use efficiency in agricultural systems in arid and SAT is 35 to 50%. 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 sub-humid 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 agro-ecosystems, green water productivity may improve from approximately 3500 m^3/t to less than 2000 m^3/t. This is a result of the dynamic nature of water productivity improvements when moving from very low yields to higher yields. 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.

Discard Artificial Divide Between Irrigated and Rainfed Agriculture

Adopt integrated water resource management 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 absence of suitable policies and mechanisms for sustainable use of groundwater resources, benefits of watershed programmes can easily be undone in short period with overexploitation of the augmented water resources (Sreedevi *et al.*, 2006). Cultivation of water inefficient crops like rice and sugarcane need to be controlled through suitable incentive mechanisms for rainfed irrigated crops and policy to be evolved 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. This will benefit small and marginal farmers through increased productivity per unit of resource. A large benefit of watershed programmes has been missed due to compartmentalized approach. Thus, there is an urgent need to bring in convergence as it has benefits in manifold. It is likely to be win-win for all the stakeholders including line departments involved in improving rural livelihoods (Wani *et al.*, 2003, 2003b).

New institutional mechanisms are also needed at district, state, and national level to converge various watershed programmes implemented by several ministries and development agencies to enhance the impact and efficiency by overcoming duplicity and confusion. 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 NRAA have also emphasized the need for convergence and collective action (GOI 2008). These are welcome developments, however, it is just a beginning and lot more still needs to be done to provide institutional and policy support for development of rainfed areas. Thus, it has become increasingly clear that water management for rainfed agriculture requires a landscape perspective, and involves cross-scale interactions from farm household scale to watershed/catchment scale.

Enhancing partnerships and institutional innovations through the consortium approach was major impetus for harnessing community watershed's potential to reduce households' poverty (Wani *et al.*, 2003). Complex issues were effectively addressed by the joint efforts of ICRISAT and in collaboration with key partners namely NARSs, non-governmental organizations (NGOs), government organizations, agricultural universities, community-based organizations and other private interest groups with farm households as the key decision makers. In self-help groups (SHGs), like village seedbanks, these were established not just to provide timely and quality seeds but to provide technical support and building the capacity of members like women for management, conservation and livelihood development activities. 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). As demonstrated by ICRISAT, the strongest merit of consortium approach is in the area of capacity building where farm households are not the sole beneficiaries. Researchers, development workers and students of various disciplines are also trained, and policymakers from the NARSs sensitized on the entire gamut of community watershed activities. Private-public partnership has provided the means for increased investments not only for enhancing productivity but also for building institutions as engines for people-led NRM.

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 rather than only soil and water conservation approach. Strengths of rainfed areas using available water resources efficiently through involvement of private entrepreneurs and value addition can be harnessed by linking small and marginal farmers to markets through public-private partnership business model for watershed management (Wani *et al.*, 2008, 2008a).

Pilot-Scale Model Community Watershed

Based on detailed studies and synthesis of the results, impacts, shortcomings, learnings from large number of watershed programmes and on-farm experiences gained, ICRISAT-led consortium developed an innovative farmers' participatory consortium model for integrated watershed management (Wani *et al.*, 2002, 2003b, 2003c). ICRISAT-led watershed espouses the IGNRM approach where activities are implemented at landscape level at benchmark sites representing the different agroecoregions of the SAT. The entire process revolves around the four E's (empowerment, equity, efficiency and environment), which are addressed by adopting specific strategies prescribed by the four C's (consortium, convergence, cooperation 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.*, 2003b).

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.
- Integrated water resource management and holistic system approach through convergence for improving livelihoods as against traditional compartmental approach.

- A consortium of institutions for technical backstopping.
- Knowledge-based entry point to build rapport with community and enhanced participation of farmers and landless people through empowerment.
- Tangible economic benefits to individuals through on-farm interventions enhancing efficiency of conserved soil and water 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 and rehabilitation of wastelands for improved livelihoods and protecting the environment.

Multiple Benefits and Impacts

Through the use of new tools [i.e. remote sensing, Geographical Information Systems (GIS) 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 in the watershed communities is evident in the transformation of their economies. The ICRISAT model ensured improved productivity with the adoption of cost-efficient Water Harvesting Structures (WHS) as an entry point for improving livelihoods. 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. The model has provision for improving the capacity of farm households through training and networking and for alleviating livelihood enhanced participation especially of the most vulnerable groups like women and the landless.

Building on social capital made the huge difference in addressing rural poverty of watershed communities. This is evident in the case of Adarsha Watershed, Kothapally in Andhra Pradesh, India. Today, it 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 (Figure 2). The villagers proudly professed: "*We did not face any difficulty for water even during the drought year of 2002. When surrounding villages had no drinking water, our wells had sufficient water.*" To date, the village prides itself with households owning 5 tractors, 7 lorries and 30 auto-rickshaws. People from surrounding villages come to Kothapally for on-farm employment. With more training on livelihood and enterprise development, migration is bound to cease.

Crop Livestock integration is another facet harnessed for poverty reduction. The Lucheba watershed, Guizhou province of southern China has transformed its economy through modest injection of capital-allied contributions of labour and finance, to create basic infrastructures like access to roads and drinking water supply. With technical support from the consortium, 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 cropping technology was also effective in controlling erosion and increasing farm income in sloping lands. 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.*, 2006b). 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. A complete turnaround in livelihood system of farm households was inevitable in ICRISAT-led watersheds.

Increasing crop productivity is a common objective in all the watershed programmes; and the enhanced crop productivity is achieved after the implementation of soil and water conservation practices along with appropriate crop and nutrient management. For example, the implementation of improved crop management technology in the benchmark watersheds of Andhra Pradesh increased the maize yield by 2.5 times (Table 5) and sorghum yield by threefold (Wani *et al.*, 2006a). Overall, in the 65 community watersheds (each measuring approximately 500 ha), implementing 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 threefold to fourfold (2.8–3.5 t/ha) as compared with baseline yields (0.5 to 1.0 t/ha), reducing the yield gap between potential farmers' yields. A reduction in nitrogen fertilizer (90–120 kg urea per ha) by 38%

increased maize yield by 18%. In Tad Fa watershed of northeastern Thailand, maize yield increased by 27–34% with improved crop management.

Improving water availability in the watersheds was attributed to efficient management of rainwater and *in-situ* conservation, establishment of WHS and improved groundwater levels. Even after the rainy season, the water level in wells nearer to WHS sustained good groundwater yield. In the various watersheds of India like Lalatora (in Madhya Prdesh), treated area registered a groundwater level rise by 7.3 m. At Bundi, Rajasthan, the average rise was 5.7 m and the irrigated area increased from 207 ha to 343 ha. In Kothapally watershed in Andhra Pradesh, the groundwater level rise was 4.2 m in open wells (Figure 3). The various WHS resulted in an additional groundwater recharge per year of approximately 4,28,000 m^3 on the average. With this improvement in groundwater availability, the supply of clean drinking water was guaranteed. In Lucheba watershed in China, a drinking water project, which constitutes a water storage tank 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. Earlier every farmer's household used to spend 2–3 hours per day fetching drinking water.

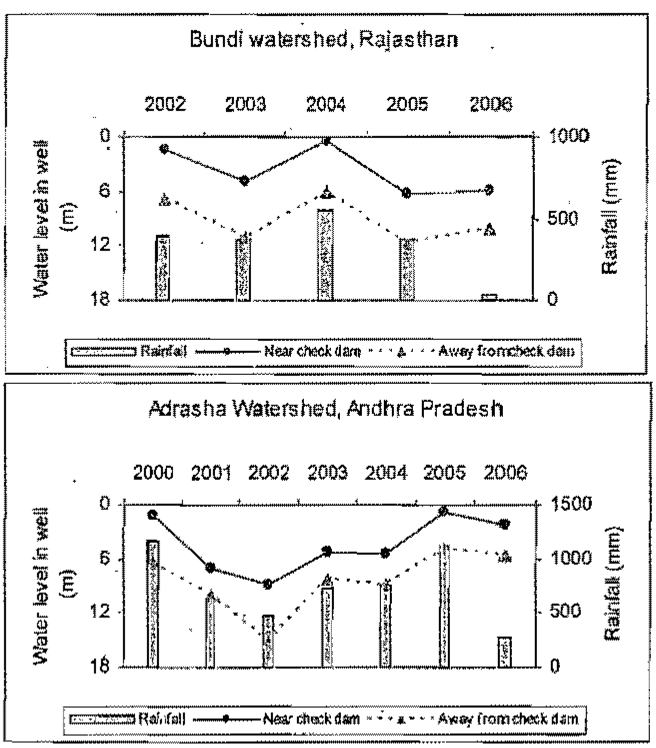

Fig. 3: The impact of watershed interventions on groundwater levels at two benchmark sites in India. (Note: Estimated additional groundwater recharge due to watershed interventions is 6,75,000 m^3/yr in Bundi watershed and 4,27,800 m^3/yr in Adarsha Watershed)

This was the main motivation for the excellent farmers' participation in the project. 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 (Wani *et al.*, 2006b).

Supplemental irrigation can play a very important role in reducing the risk of crop failures and in optimizing the productivity in the SAT. In these regions, there is good potential for delivering excess rainwater to storage structures or groundwater because even under improved systems, there is loss of 12–30% of the rainfall as runoff. Striking results were recorded from supplemental irrigation on crop yields in ICRISAT benchmark watersheds in Madhya Pradesh. On-farm studies made during 2000–03 postrainy seasons, showed that chickpea yield (1.25 t/ha) increased by 127% over the control yield (0.55 t/ha); and groundnut pod yield (1.3 t/ha) increased by 59% over the control yield (0.82 t/ha) by application of two supplemental irrigations of 40 mm. Similar yield responses in mung bean and chickpea crops were obtained from supplemental irrigation at the ICRISAT center in Patancheru (Pathak *et al.*, 2008).

Sustaining development and protecting the environment are the two-pronged achievements of the watersheds. The effectiveness of improved watershed technologies was evident in reducing runoff volume, peak runoff rate and soil loss and improving 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 (194 mm) and soil loss less than 1/7th (4.21 t/ha) as compared to the conventional system (473 mm runoff and soil loss 31.2 t/ha). This holds true with peak runoff rate where the reduction is approximately one-third (Table 6).

Large number of fields (80–100%) in the SAT were found severely deficient in zinc, boron and sulphur as well as nitrogen and phosphorus. Amendment of soils with the deficient micro- and secondary nutrients increased crop yields by 30 to 70%, resulting in overall increase in water and nutrient use efficiency. Introduction of IPM in cotton and pigeonpea substantially reduced the number of chemical insecticidal sprays in Kothapally, India during the season and thus reduced the pollution of water bodies with harmful chemicals (Rego *et al.*, 2007). Introduction of Integrated Pest Management (IPM) and

Table 6: Seasonal Rainfall, Runoff and Soil Loss from Different Benchmark Watersheds in India and Thailand

Watershed	Seasonal Rainfall (mm)	Runoff (mm)		Soil Loss (t/ha)	
		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

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, which brought into use 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.

Improved land and water management practices along with integrated nutrient management comprising application of inorganic fertilizers and organic amendments (such as crop residues, vermicompost, farm manures and *Gliricidia* loppings) as well as crop diversification with legumes not only enhanced productivity but also improved soil quality. Increased carbon sequestration of 7.4 t/ha in 24 years was observed with improved management options in a long-term watershed experiment at ICRISAT. By adopting fuel-switch for carbon, women SHGs in Powerguda (a remote village of Andhra Pradesh, India) have pioneered the sale of carbon units (147 t CO_2 C) to the World Bank from their 4,500 *Pongamia* trees, seeds of which are collected for producing saplings for distribution/ promotion of biodiesel plantation. Normalized Difference Vegetation Index (NDVI) estimation from the satellite images showed that within four years, vegetation cover could increase by 35% in Kothapally. 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; Sahrawat *et al.*, 2005; Wani *et al.*, 2005).

Conserving biodiversity in the watersheds was engendered through participatory NRM. The Index of Surface Percentage of Crops (ISPC), Crop Agro-biodiversity Factor (CAF), and surface variability of main crops changed as a result of integrated watershed management interventions. Pronounced agro-biodiversity impacts were observed in Kothapally watershed where farmers now grow 22 crops in a season with a remarkable shift in cropping pattern from cotton (200 ha in 1998 to 100 ha in 2002) to a maize/pigeonpea intercrop system (40 ha in 1998 to 180 ha in 2002), thereby changing the CAF from 0.41 in 1998 to 0.73 in 2002. In Thanh Ha, Vietnam the CAF changed from 0.25 in 1998 to 0.6 in 2002 with the introduction of legumes (Wani *et al.*, 2005).

Scaling-up

Most farming problems require integrated solutions, with genetic, management-related, and socioeconomic components. In essence, plant breeders and NRM scientists must integrate their work with that of private and public sector change agents, to develop flexible cropping systems that can respond to rapid changes in market opportunities and climatic conditions. ICRISAT in partnership with NARSs has conceived, developed and successfully evaluated an innovative farmers' participatory consortium model for integrated watershed management. The model includes the consortium approach and adopts the concept of convergence in every activity in the watershed (Sreedevi and Wani 2008).

The new paradigm for upgrading rainfed agriculture can double the productivity in Asia and also reduce poverty without causing further degradation of natural resource base. 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. Along with water use, equity issues concerning 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. Use of ICTs to cover the last mile to reach the un-reached is a must as the existing extension mechanisms are in sufficient in meeting the ever growing demand as well as to share the new and vast body of knowledge with the large number of small and marginal farmers (Sreedevi and Wani 2008).

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