FOOD AND WATER SECURITY

U. ASWATHANARAYANA
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Chapter 9

Improved livelihoods and food security through unlocking the potential of rainfed agriculture

Suhas P. Wani[1], T.K. Sreedevi[1], Johan Rockström[2], Thawilkal Wangkahart[3], Y.S. Ramakrishna[4], Yin Dixin[5], A.V.R. Kesava Rao[1] & Zhong Li[6]

[1] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India; [2] Stockholm Environment Institute (SEI), Stockholm, Sweden; [3] c/o Agricultural Research and Development, Region 3, Muang, Khan Kaen, Thailand; [4] Central Research Institute for Dryland Agriculture (CRIDA), Santoshnagar, Hyderabad, Andhra Pradesh, India; [5] Guizhou Academy of Agricultural Sciences (GAAS), Integrated Rural Development Center, Guiyang, Guizhou Province, China; [6] Yunnan Academy of Agricultural Sciences (YAAS), Kunming, Yunnan Province, China

9.1 Importance of rain-fed agriculture

Eighty per cent of the world's agricultural land area is rainfed and generates 58% of the world's staple foods (SIWI, 2001). The importance of rainfed agriculture varies regionally, but produces most food for poor communities in developing countries. In sub-Saharan Africa (SSA) more than 95% of the farmed land is rainfed, while the corresponding figure for Latin America is almost 90%, for South Asia about 60%, for East Asia 65% and for Near East and North Africa 75%. Farming systems in sub-Saharan Africa and Latin America are almost exclusively rainfed, while a predominant blue water dependence in irrigation is concentrated in the West Asian (>80% dependence) and North African regions (>60% dependence) (Rockström, 2003). In South and East Asia the picture is mixed, with countries depending in varying degrees on both rainfed and irrigated agriculture (e.g., India where 60% of water use in agriculture are estimated to originate from directly infiltrated rainfall, while 40% originates from extraction of river and groundwater for irrigation). A survey of "irrigation schemes" in Tanzania has shown that over 80% of them are supplementary irrigated systems where the bulk of water for crops is supplied by direct rainfall (MAFS, Tanzania Ministry of Agriculture, 2003).

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 and they depend on agriculture for their livelihood. About half of the hungry live in smallholder farming households, while two-tenths are landless. About 10% are pastoralists, fish folk and forest users (Sanchez *et al.*, 2005). Hungry people are highly vulnerable to crises and hazards. The crises may be caused by natural disasters, such as major droughts or floods. Water (freshwater) is a limiting natural resource and plays an important role in providing livelihood support for rural populations where agriculture is the key occupation. Water scarcity is a significant problem for farmers in Africa, Asia, and the near East where 80–90 per cent of water

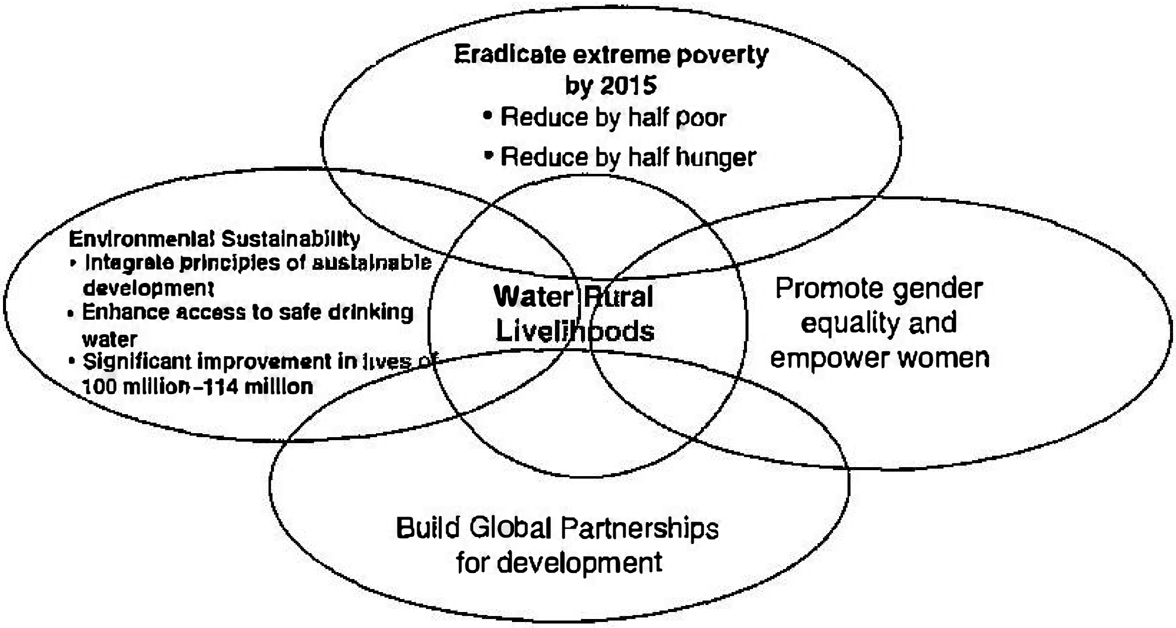


Figure 9.1 Water an important driver for the millennium development goals.

withdrawals are used for agriculture (FAO 2000, Rosegrant et al., 2002). Water a finite resource, the very basis of life and the single most important feature of our planet, is the most threatened natural resource today. Water is most important driver for four of the millennium development goals (MDGs) as shown in the Figure 9.1. In the context of four MDGs contribution of water resources management through direct interventions are suggested to achieve the milestones by 2015.

Improving social capital investments in water infrastructure as a catalyst for regional development and pivotal role of community-based organizations (CBOs) in water management is highlighted by the task force on the MDG. Rain-fed agriculture that constitutes the livelihood base for the vast majority of rural inhabitants (about 75 per cent of the poor in South Asia, and about 80 per cent of the population in east Africa) in the developing countries is a source of food security, employment and cash income (Rockstrom *et al.*, 2003).

9.2 Constraints in rainfed agriculture areas

An insight into the rain-fed regions shows 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 a&c, Rockstrom *et al.*, 2007). Drought and land degradation are interlinked in 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 to meet the MDG of halving the number of food insecure poor by 2015. A global assessment of the extent and form of land degradation showed that 57% of the total area of drylands occurring in two major Asian countries, namely China (178.9 m ha) and India (108.6 mha), are degraded (UNEP, 1997). Accelerated erosion resulting in

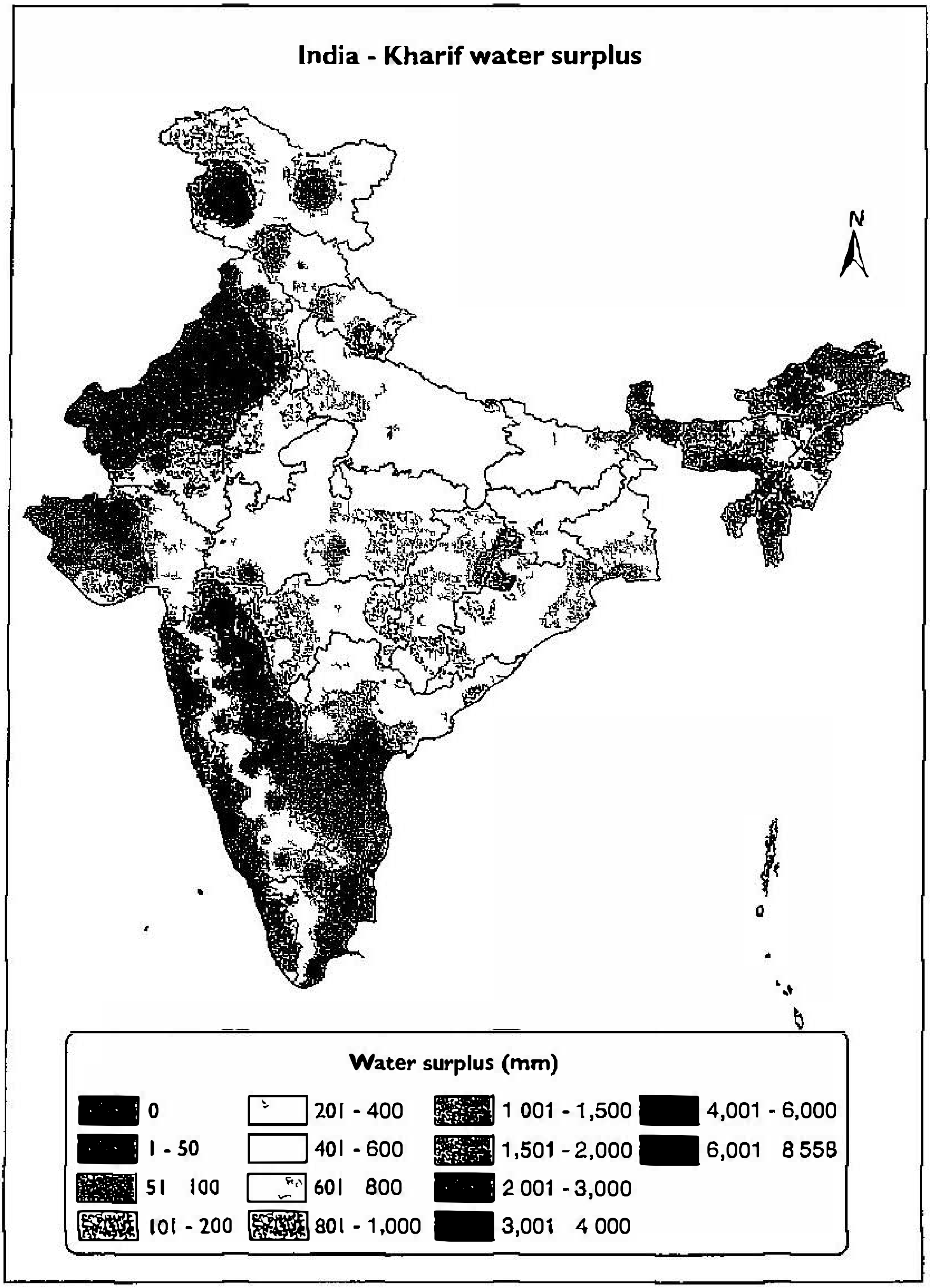


Plate 9 1 Excess water available for harvesting as runoff in the states of SAT India (see *Color plate 9 1*)

the loss of nutrient rich top fertile soil however, occurs nearly everywhere where agriculture is practiced and is irreversible The torrential character of the seasonal rainfall creates high risk for the cultivated lands In India, alone some 150 million ha are affected by water erosion and 18 m ha by wind erosion Thus, erosion leaves behind

Table 9.1 Annual water balance characters (all values in mm).

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

an impoverished soil on one hand, and siltation of reservoirs and tanks on the other. This degradation induced source of carbon emissions contribute also to far reaching global warming consequences. In addition imbalanced use of nutrients in agriculture by the farmers results in mining of soil nutrients. Recent studies in India revealed that 80 to 100% of the farmers' fields were found critically deficient in zinc, boron, and sulphur in addition to nitrogen and organic carbon (Wani *et al.*, 2006a). If the current production practices are continued, developing countries in Asia and Africa will face a serious food shortage in the very near future.

Weekly water balances of selected watersheds in China, Thailand and Vietnam were completed based on long-term agrometeorological data and soil type. The water balance components included potential evapotranspiration (PET), actual evapotranspiration (AET), water surplus (WS) and water deficit (WD). PET varied from about 890 mm at Lucheba in China to 1890 mm at Tirunelveli in South India (Table 9.1). AET values are relatively lower at the watersheds in China and India compared to those in Thailand and Vietnam. Varying levels of water surplus and water deficit occur at the watersheds. Among all the locations, Tirunelveli in India has the largest water deficit (1347mm) and no water surplus. Chine in Vietnam has the largest water surplus of 907 mm. These analyses defined the dependability for moisture availability for crop production and opportunities for water harvesting and groundwater recharge.

9.3 Potential of rainfed agriculture

In several regions of the world rainfed agriculture generates among the world's highest yields. These are predominantly temperate regions, with relatively reliable rainfall and inherently productive soils. Even in tropical regions, particularly in the sub-humid and humid zones, agricultural yields in commercial rainfed agriculture exceed 5–6 $\mathrm{t\,ha^{-1}}$ (Rockström and Falkenmark, 2000; Wani *et al.*, 2003a, b). At the same time, the dry sub-humid and semi-arid regions have experienced the lowest yields and the weakest productivity improvements. Here, yields oscillate in the region of 0.5–2 $\mathrm{t\,ha^{-1}}$, with an average of 1 $\mathrm{t\,ha^{-1}}$, in sub-Saharan Africa, and 1–1.5 $\mathrm{t\,ha^{-1}}$, in the SAT Asia and Central and West Asia and North Africa (CWANA) for rainfed

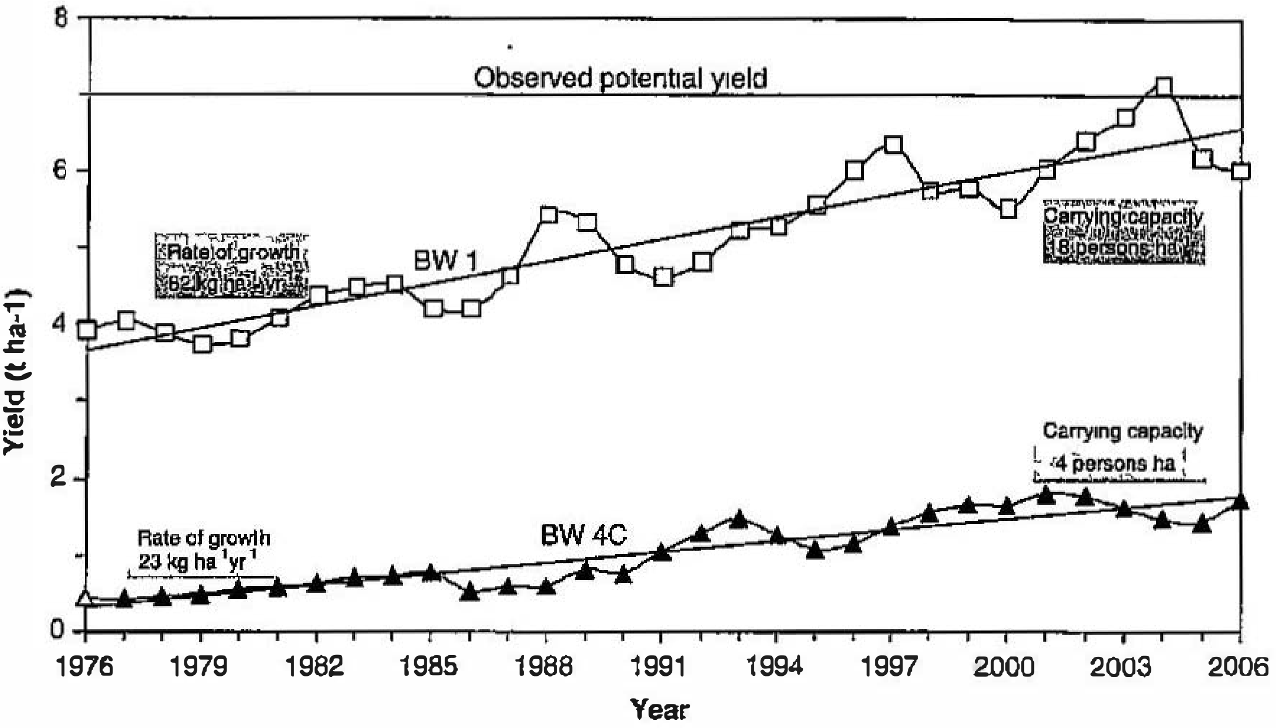


Plate 9.2 Three-year moving average of sorghum and pigeon pea grain yield under improved management and on farmers' fields in a deep Vertisol catchment, Patancheru, India. (See *Colour plate 9.2*)

agriculture (Rockström, and Falkenmark 2000; Wani *et al.*, 2003a, b, Rockstrom *et al.*, 2007). 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 rainfed agriculture. Improved systems of sorghum/pigeonpea intercrops produced higher mean grain yields (5.1 $\mathrm{t\,ha^{-1}}$ per yr) compared to 1.1 $\mathrm{t\,ha^{-1}}$ per yr, average yield of sole sorghum in the traditional (farmers') post-rainy system where crops are grown on stored soil moisture (Plate 9.2). The annual gain in grain yield in the improved system was 82 $\mathrm{kg\,ha^{-1}}$ per yr compared with 23 $\mathrm{kg\,ha^{-1}}$ per yr in the traditional system. The large yield gap between attainable yield and farmers' practice as well as between the attainable yield of 5.1 $\mathrm{t\,ha^{-1}}$ and potential yield of 7 $\mathrm{t\,ha^{-1}}$ shows that a large potential of rainfed agriculture remains 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 300 $\mathrm{kg\,C\,ha^{-1}}$ per year (Wani *et al.*, 2003b). Yield gap analyses, undertaken by the Comprehensive Assessment, for major rainfed crops in semi-arid regions in Asia (Fig 9.4) and Africa and rainfed wheat in West Asia and North Africa (WANA), reveal large yield gaps, with farmers' yields being a factor of 2–4 lower than achievable yields for major rainfed crops grown in Asia and Africa (Rockstrom *et al.*, 2007).

Farmers' yields continue to be very low compared to the experimental yields (attainable yields) as well as simulated crop yields (potential yields), resulting in a very significant yield gap between actual and attainable rainfed yields. The difference is largely explained by inappropriate soil, water, and crop management options at the farm level, combined with persistent land degradation.

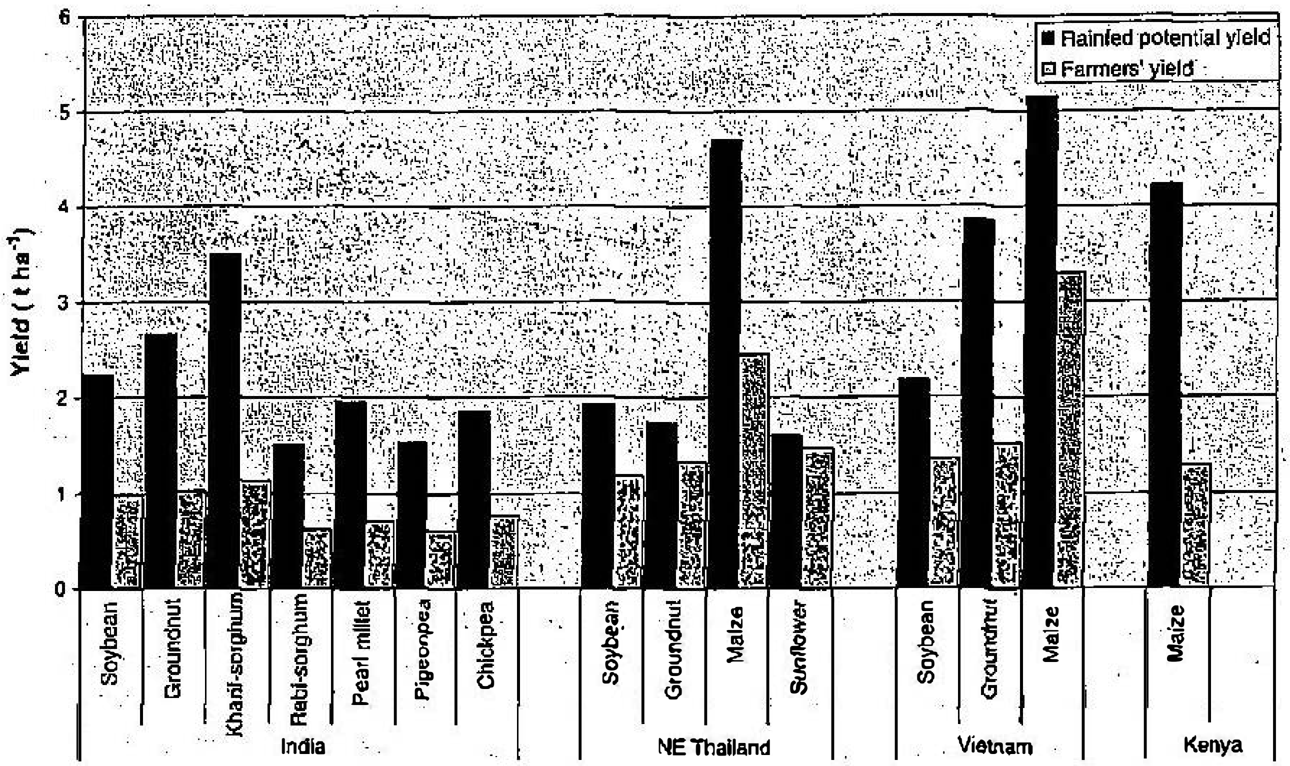


Figure 9.2 Yield gap analysis of important rainfed crops in different countries.

The vast potential of the rainfed agriculture need to be unlocked through knowledge-based management of natural resources for increasing the productivity and incomes to achieve food secured developing world.

9.4 Need for a new paradigm for water management in rainfed agriculture

For enhancing rainwater use efficiency in rainfed agriculture, management of water alone can not result in enhanced water productivity as in these areas crop yields are limited by more 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 (Wani *et al.*, 2006a).

Based on the Policy on water resource management for agriculture remains focused on irrigation, and the framework for integrated water resource management (IWRM) at catchment and basin scales are primarily concentrated on allocation and management of blue water in rivers, groundwater and lakes. The evidence from the comprehensive assessment of water for food and poverty reduction indicated water for agriculture is larger than irrigation, and there is an urgent need for a widening of the policy scope to include explicit strategies for water management in rainfed agriculture including grazing and forest systems. However, what is needed is effective integration so as to have a focus on the investments options on water management across the continuum from rainfed to irrigated agriculture. This is the time to abandon the obsolete sectoral divide between irrigated and rainfed agriculture, which would place water resource management and planning more centrally in the policy domain of agriculture at large, and not as today, as a part of water resource policy (Molden *et al.*, 2007).

Furthermore, the current focus on water resource planning at the river basin scale is not appropriate for water management in rainfed agriculture, which overwhelmingly occurs on farms of <5 ha at the scale of small catchments, below the river basin scale. Therefore, focus should be to manage water at the catchment scale (or small tributary scale of a river basin), opening for much needed investments in water resource management also in rainfed agriculture (Rockström *et al.*, 2007).

In several countries, central and state governments have emphasised management of rainfed agriculture under various programmes. Important efforts for example have been made under the watershed development programmes in India. Originally, these programmes were implemented by different ministries such as the Ministry of Agriculture, the Ministry of Rural Development and the Ministry of Forestry, causing difficulties for integrated water management. Recently, steps were taken to unify the programme according to the "Hariyali Guidelines" (Wani *et al.*, 2006a). Detailed meta analysis of 311 watershed case studies in India revealed that watershed programs are silently revolutionalizing rainfed areas with positive impacts (B:C ratio of 1:2.14, IRR of 22%, increased cropping intensity by 63%, increased irrigated areas by 34%, reduced run off by 13% and increased employment by 181 person days per year per ha). However, 65% of the watersheds were performing below average performance as they lacked community participation, programs were supply driven, equity and sustainability issues were eluding and compartmental approach was adopted (Joshi *et al.*, 2004).

Based on detailed studies and synthesis of the results, impacts, shortcomings, learnings from large number of watershed programs and on-farm experiences gained, ICRISAT-led consortium developed an innovative farmers' participatory consortium model for integrated watershed management (Wani *et al.*, 2002, 2003a,c). ICRISAT-led watershed espouses the Integrated Genetic Natural Resources Management (IGNRM) approach where activities are implemented at landscape level. Research and development (R&D) interventions at landscape level were conducted at benchmark sites representing the different SAT agroecoregions. 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).

In 2005, the National Commission on Farmers adopted 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 Authority for Development of Rainfed Areas (NADORA) with the mandate to converge various programmes for integrated development of rainfed agriculture in the country. These are welcome developments where policy makers have realised the need to develop rainfed areas for reducing poverty and increasing agricultural production. 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

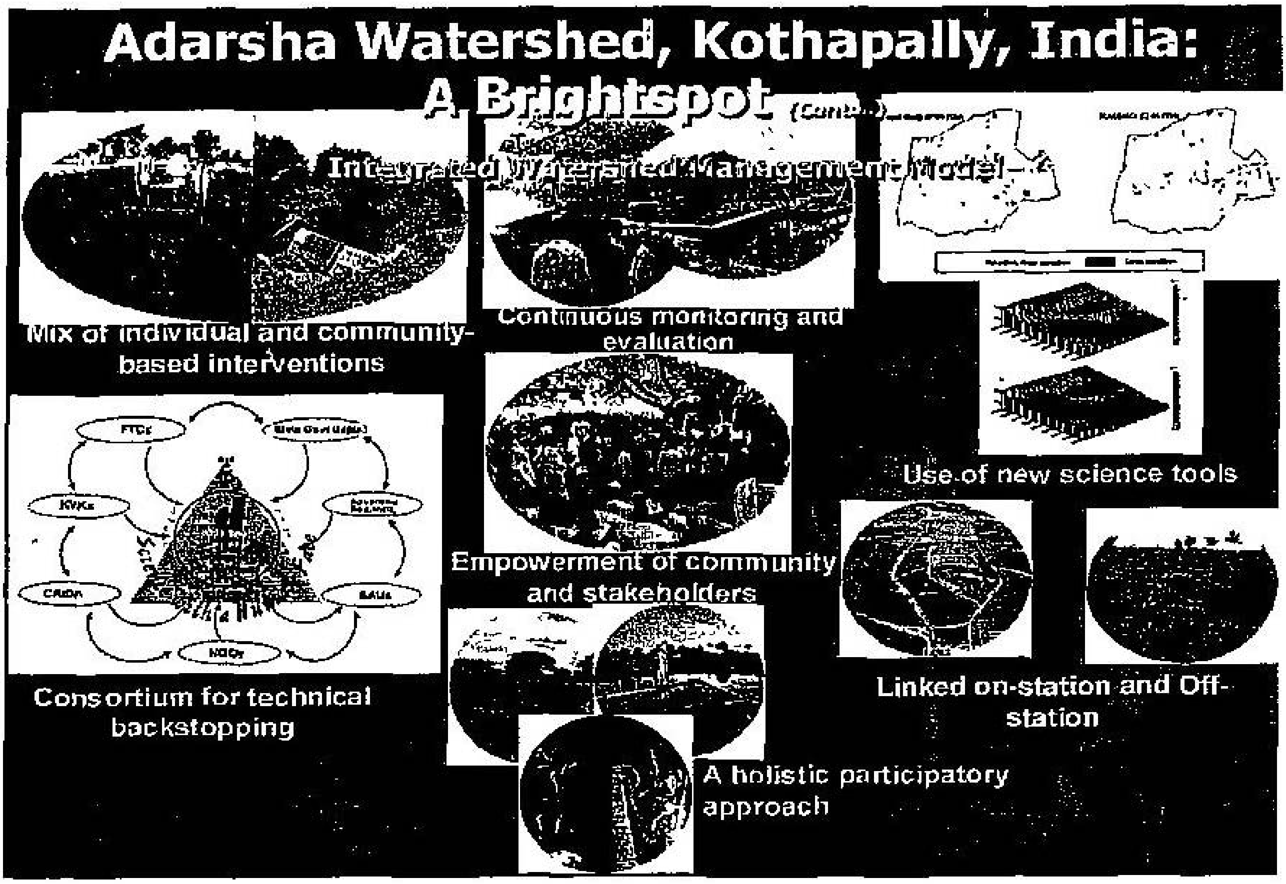


Plate 9.3 An innovative consortium model for integrated watershed management. (See *Colour plate 9.3*)

involves cross-scale interactions from farm household scale to watershed/catchment scale and upstream-down stream linkages.

9.5 Shifting non-productive evaporation to productive transpiration

Rainwater use efficiency in arid and SAT is 35 to 50% and up to 50% of the rainwater falling on crop or pasture fields is lost as non-productive evaporation. This is a key window 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), where management of soil physical conditions, *soil fertility*, crop varieties and agronomy are combined to shift the evaporative loss into useful transpiration by plants, is a particular opportunity in arid, semi-arid and dry-subhumid regions (Rockstrom *et al.*, 2007).

Field measurements of rainfed grain yields and actual green water flows indicate that when doubling yields from 1 to 2 t ha^{-1} in semi-arid tropical agro-ecosystems, green water productivity may improve from approximately 3500 m^3/t^{-1} to less than 2000 m^3/t^{-1}. 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 high, as the leaf area coverage of the soil is low, which together results in high losses of rainwater as evaporation from soil. When yield levels increase, shading of soil improves, and when yields reach 4-5 t/ha^{-1} and above, the canopy density is so high that the opportunity to reduce evaporation in favour of increased transpiration reduces, lowering the relative improvement of water productivity. This indicates that large opportunities of improving water productivity are found in low-yielding farming systems (Rockström, 2003; Oweis *et al.*, 1998), i.e., particularly in rainfed agriculture as compared to irrigated agriculture where water productivity already is higher due to better yields.

9.6 Investments in rainfed areas produce multiple benefits

Through the use of new science tools (i.e. remote sensing, GIS, and simulation modeling) twinned 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 to SAT resource-poor farm households.

9.6.1 *Reducing rural poverty*

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 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. Provision for improving the capacity of farm households through training and networking and for alleviating livelihood enhanced participation most especially of the most vulnerable groups like women and the landless. The self-help groups (SHGs) common in the watershed villages of India and an improved initiative in China provided income and empowerment of women. The environmental clubs whose conceptualization is traced from Bundi watershed of Rajasthan, India inculcated environmental protection, sanitation and hygiene among the children.

Building on social capital made the huge difference in addressing rural poverty of watershed communities. A case in point is Kothapally watershed. 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$795 compared with the neighboring non-watershed village with US$622 (Fig. 9.3). 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. There were evidences to suggest that with more training on livelihood and enterprise development, migration is bound to cease. Between 2000 and 2003, investments in new livelihood enterprises such as seed oil mill, tree nursery, and worm composting increased average income by 77% in Powerguda, a tribal village in Andhra Pradesh.

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 labor and finance, to create basic infrastructures like access road and drinking water supply. With technical

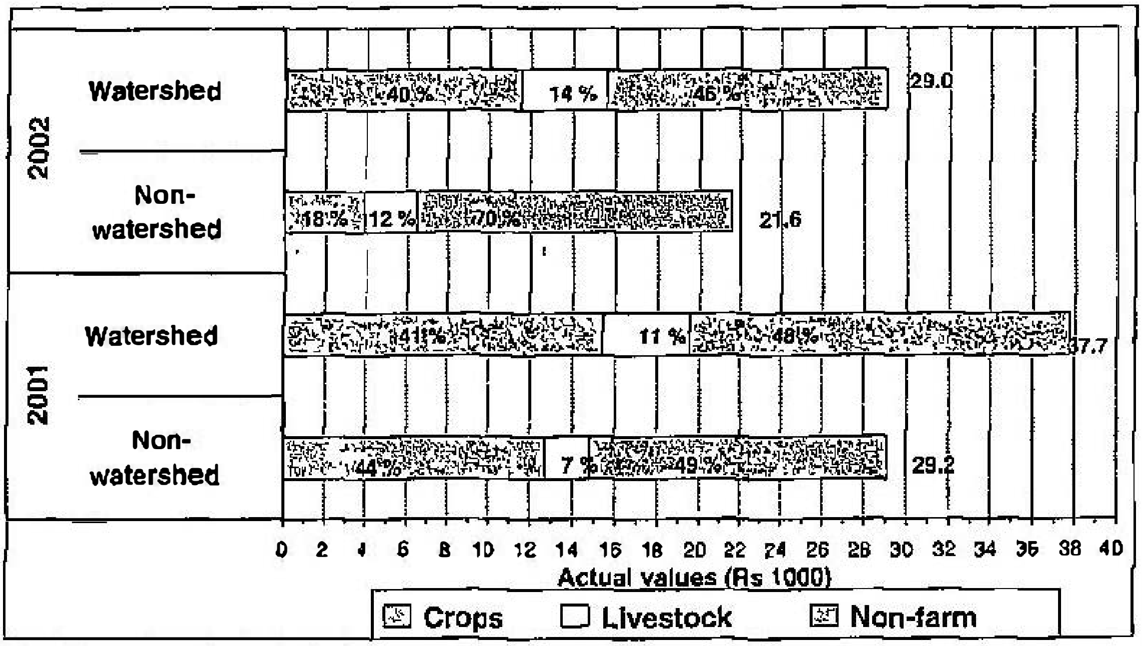


Figure 9.3 Income stability and resilience effects during drought year (2002) in Adarsha watershed, Kothapally, AP, India.

support from the consortium, the farming system was intensified from rice and rape seed to tending livestock (pig raising) and horticultural crops (fruit trees like *Zizipus*; vegetables like beans, peas, sweetpotato) and groundnuts. Forage production specifically wild buckwheat as an alley crop 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 have intensified livestock activities like breed improvement (artificial insemination and natural means) and livestock center/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.

9.6.2 *Increasing crop productivity*

Increasing crop productivity is common in all the watersheds and evident in so short period from the inception of watershed interventions. To cite few cases, in benchmark watersheds of Andhra Pradesh, improved crop management technologies increased maize yield by 2.5 times and sorghum by 3 times (Wani *et al.*, 2006a). Over-all, in 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 as an intercrop (40–110%). In Thanh Ha watershed of Vietnam, yields of soybean, groundnut and mungbean increased by three to four folds (2.8–3.5 t ha^{-1}) as compared with baseline yields (0.5 to 1.0 t ha^{-1}) reducing the yield gaps between potential farmers' yields. A reduction in N fertilizer (90–120 kg urea ha^{-1}) by 38% increased maize yield by 18%. In Tad Fa watershed

Table 9.2 Crop yields in Adarsha watershed, Kothapally, during 1999–2005.

Crop	1998 Baseline*	Yield (kg ha^{-1})						
		1999	2000	2001	2002	2003	2004	2005
Sole maize	1500	3250	3750	3300	3480	3920	3420	3920
Intercropped maize	–	2700	2790	2800	3080	3130	2950	3360
(Traditional)		700	1600	1600	1800	1950	2025	2275
Intercropped	190	640	940	800	720	950	680	925
pigeonpea		200	180	–	–	–	–	–
(Traditional)								
Sole sorghum	1070	3050	3170	2600	2425	2290	2325	2250
Intercropped sorghum	–	1770	1940	2200	–	2110	1980	1960

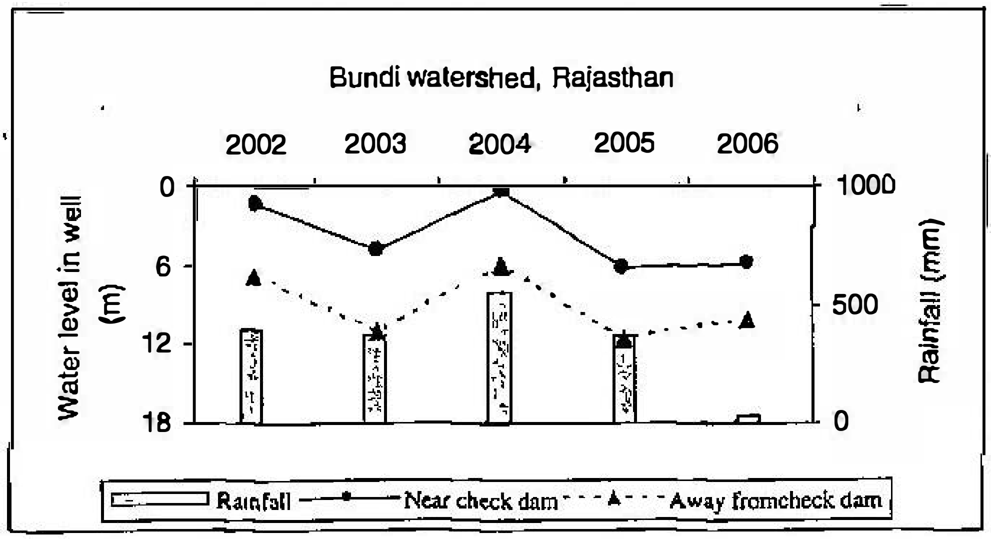
of northeastern Thailand, maize yield increased by 27–34% with improved crop management.

9.6.3 *Improving water availability*

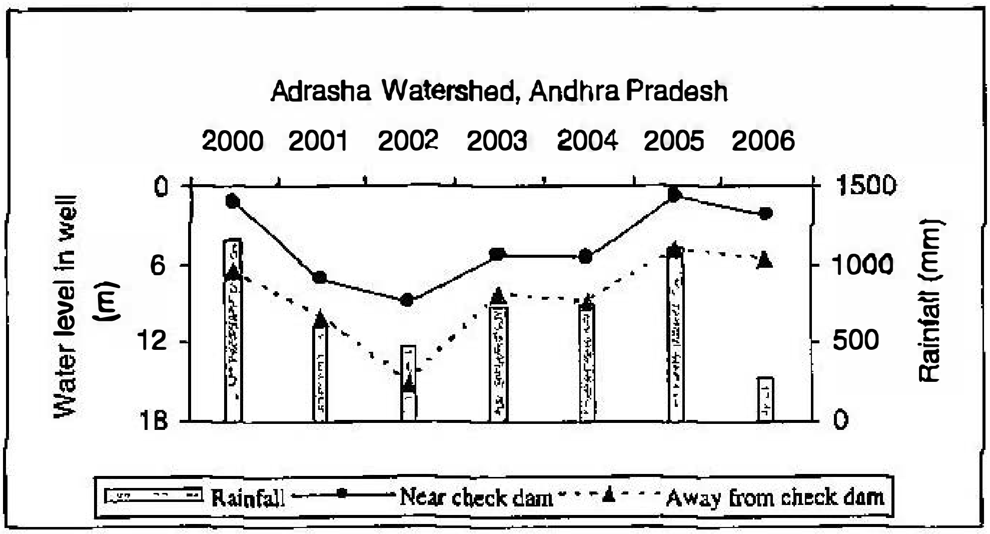
Improving water availability in the watersheds was attributed to efficient management of rainwater and *in-situ* conservation; establishing water harvesting structures (WHS) improved groundwater levels. Findings in most of the watershed sites reveal that open wells located near WHS have significantly higher water levels compared to those away from the WHS. 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, treated area registered a groundwater level rise by 7.3 m. At Bundi, the average rise was at 5.7 m and the irrigated area increased from 207 ha to 343 ha. In Kothapally watershed, the groundwater level rise was at 4.2 m in open wells (Fig. 9.4). 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, 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. This was the main motivation for the excellent farmers' participation in the project. On the other hand, collective pumping of well water out establishing efficient water distribution system enabled farmers group to earn more income by growing watermelon with reduced drudgery for women who had to carry on head from a long distance, pumping of water from the river as a means to irrigate watermelon has provided maximum income for households in Thanh Ha watershed (Wani *et al.*, 2006b).

9.6.4 *Sustaining development and protecting the environment*

Sustaining development and protecting the environment are the two-pronged achievements of the watersheds. The effectiveness of improved watershed technologies was evident in reducing run-off volume, peak run-off rate and soil loss and improving groundwater recharge. This is particularly significant in Tad Fa watershed where



Estimated additional groundwater recharge due to watershed interventions = 6,75,000 m^3 per year.



Estimated additional groundwater recharge due to watershed interventions = 4,27,800 m^3 per year

Figure 9.4 The impact of watershed interventions on groundwater levels at two benchmark sites in India.

interventions such as contour cultivation at midslopes, vegetative bunds planted with *Vetiver*, fruit trees grown on steep slopes and relay cropping with rice bean reduced seasonal run-off to less than half (194 mm) and soil loss less than 1/7th (4.21 $t\,ha^{-1}$) as compared to the conventional system (473 mm run-off and soil loss 31.2 $t\,ha^{-1}$). This holds true with peak run-off rate where the reduction is approximately one-third (Table 9.3).

Large number of fields (80–100%) in the SAT were found severely deficient in Zn, B, and S along with N and P. Amendment of 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 integrated pest management (IPM) and improved cropping systems decreased the use of pesticides worth US\$44–66 ha^{-1}. Crop rotation using legumes in Wang Chai watershed substantially reduced N requirement for

Table 9.3 Seasonal rainfall, runoff and soil loss from different [illegible] and Thailand.

Watershed	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	1.90
Ringnodia, Madhya Pradesh, India	764	21	66	0.75	2.2
Lalatora, Madhya Pradesh, India	1046	70	273	0.63	3.2

rainfed sugarcane. 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 (INM) comprising of applications of inorganic fertilizers and organic amendments such as crop residues, vermicompost, farm manures, *Gliricidia* loppings as well as crop diversification with legumes not only enhanced productivity but also improved soil quality. Increased carbon sequestration of 7.4 $t\,ha^{-1}$ 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_2C) 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 run off water (8 vs 14 kg N ha^{-1}). Introduction of IPM in cotton and pigoenpea substantially reduced the number of chemical insecticidal sprays during the season and use of pesticides reduced the pollution of water bodies with harmful chemicals. Reduced runoff and erosion reduced risk of downstream flooding and siltation of water bodies that directly improved environmental quality in the watersheds.

9.6.5 *Conserving biodiversity*

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 (IWM) 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 to 180 ha), 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 Similarly, rehabilitation of the common property resource land in Bundi watershed through the collective action of the community ensured the availability of fodder for all the households and income of US $1670 y^{-1} for the SHG through sale of grass to the surrounding villages Aboveground diversity of plants (54 plant species belonging to 35 families) as well as belowground diversity of microorganisms (21 bacterial isolates, 31 fungal species and 1 6 times higher biomass C) was evident in rehabilitated CPR as compared to the degraded CPR land (9 plant species, 18 bacterial isolates and 20 fungal isolates of which 75% belong to *Aspergillus* genus)

9.6.6 *Promoting natural resource management (NRM) at landscape level*

Promoting natural resource management (NRM) at landscape level is the scale of work done by the ICRISAT consortium Benefiting from data obtained from using new science tools like remote sensing, a comprehensive understanding of the effects of the changes (i e vegetation cover on degraded lands) in the watersheds is made This in turn has provided the indicators to assess agricultural productivity Promoting NRM at the landscape level by using tools that provide the needed database is anticipated to have better impact because of the possible integration of all the factors (natural resources with the ancillary information)

While there were some interventions at plot to farm level, the impact factors of NRM such as sustainability of production, soil and water quality, and other environment resources have been looked at from a landscape perspective This accounts for some successes in addressing concerns on equity issue like benefits for the poorest people such as the landless who are unable to take advantage of improved soil/water conditions and expansion of water intensive crops triggering renewed water stress These remain as legitimate challenges of a holistic thinking, which can be better unraveled from a landscape scale To date, the articulation of this recognition is seen in policy recommendations for serious attention to capacity building and not just for construction activities

Equal concern was made on on-site and off-site impacts The effect of water conservation at the upper ridge to downstream communities has been factored in Water harvesting structures specifically the rehabilitation of the *nala* (drain) bund at the upper portion in Bundi watershed allowed irrigation of 6 6 ha at the downstream part Another case is the Aniyala watershed located at the lower topo-sequence of Rajasamadhiyala watershed Excess water flows of the 21 water harvesting structures in Rajasamadhiyala cascades into Aniyala This has increased groundwater recharge by 25% and improved the groundwater source by 50% in a normal rainfall year Because of this, there was an increase in crop production by 25–30% (Sreedevi *et al* , 2006) The quality and number of livestock in the village improved because of water and fodder availability Off-site effects of watershed specifically equity issues is one area that needs to be strengthened for enhanced impact

9.6.7 *Enhancing partnerships and institutional innovations*

Enhancing partnerships and institutional innovations through the consortium approach was the major impetus for harnessing watershed's potential to reduce households' poverty. The underlying element of the consortium approach adapted in ICRISAT-led watersheds is engaging a range of actors with the locales as the primary implementing unit. Complex issues were effectively addressed by the joint efforts of ICRISAT and with key partners namely the national agricultural research systems (NARSs), non-government organizations (NGOs), government organizations (GOs), agricultural universities, community-based organization and other private interest groups with farm households as the key decision-makers. In SHGs, like village seed banks, these were established not just to provide timely and quality seeds. These created the venue for receiving technical support and building the capacity of members like women for the management of 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. As demonstrated by ICRISAT, the strongest merit of consortium approach is in 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 (PPP) has provided the means for increased investments not only for enhancing productivity but also for building institutions as engines for people-led natural resource management.

From another aspect, the consortium approach has contributed to scaling through the nucleus-satellite scheme and building productive alliances for further research and technical backstopping. With cooperation, a balanced R & D was implemented rather than a 'purist model' of participation or blind adherence to government guidelines. A balanced R&D in community watersheds has encouraged scientific debate and at the same time promoted development through tangible economic benefits.

The contributions of other international agricultural research centers (IARCs) like the International Water Management Institute (IWMI), International Livestock Research Institute (ILRI) and World Wildlife Fund (WWF) have become allies because of common denominators like goal (poverty reduction) and subject (water resources). It must be reckoned that while centers have their own mandates, these will have to be addressed from a holistic perspective seeking the assistance and contributions of other centers, their technical expertise and findings. This not only maximized the use of resources but the problem situation in watersheds allowed for an integrated approach requiring the alliance of institutions and stakeholders. Similarly, the various networks like the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and Cereals and Legumes Asia Network (CLAN) have provided an added venue for exchange and collaboration. This led to a strong south-south partnership.

9.7 Conclusion

Rainfed areas which constitute about 80% of cultivated areas worldwide, are also where 65 million poor people reside in the SAT. Along with water scarcity, land degradation, poverty, malnutrition and demographic pressure are important constraints, which need urgent attention. In dry sub-humid and SAT areas yields of rainfed agriculture oscillate between 1 to 1.5 t ha^{-1} as against the potential of 5 t ha^{-1} in the SAT. There is a need to have a new paradigm for water resource management in rainfed areas where at catchment scale water need to be managed in integrated manner in a continuum from rainfed to supplemented irrigation using harvested run-off water or recharged groundwater. Evidence clearly demonstrated that water alone cannot do the job of increasing productivity as other limiting factors such as nutrients, pests, low quality seeds infrastructure and lack of knowledge held back the potential. Investments in rainfed areas produce multiple benefits such as reducing poverty, developing social capital, community-empowerment, building institutions, protecting environment, reducing land degradation, conserving biodiversity, sequestering carbon and provide environmental services.

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