Sustainable Groundwater Development through Integrated Watershed Management for Food Security

Suhas P. Wani, Raghavendra Sudi and P. Pathak
International Crops Research institute for the Semi Arid Tropics (ICRISAT)
Patancheru PO, Andhra Pradesh, 502 324, India
e-mail: s.wani@cgiar.org

Abstract

Globally rain-fed agriculture is playing and will continue to play an important role for food security and sustainable agricultural development (Wani et al. 2008, 2009, Rockström et al. 2007). Rainwater is the main source of water for agriculture but its current use efficiency for crop production is low (30-45%). The Comprehensive Assessment of Water Management in Agriculture for Food and Health has discarded the artificial divide between the irrigated and rain-fed agriculture as none of these systems exist in isolation but are in a continuum from rainfed – rainfed with supplemental irrigation to fully irrigated systems (Molden et al. 2007). Groundwater is an important source for irrigated agriculture as it generally furnishes reliable and flexible inputs of water. To this extent, groundwater is instrumental in managing risk and optimizing food production in the rainfed areas. However, this reliance upon shallow aquifer systems for irrigation has turned to dependency. Depleting groundwater is a serious problem throughout Asia and more so in India as more than 22 million wells are operational in India supporting the economy.

Integrated watershed development is the strategy adopted in the country for sustainable development of dry land areas and a recent comprehensive assessment of watershed programs in India undertaken by ICRISAT-led consortium revealed that integrated watershed can become the growth engine for sustainable development of dry land areas by improving the performance of 2/3rd watersheds in the country (Wani et al. 2008). In most of the developed watersheds with concerted efforts to manage rainwater, the groundwater availability is improved not only in the watershed, but the downstream areas also benefited with increased groundwater recharge (Wani et al. 2003, Sreedevi et al. 2006, Pathak et al. 2007). Along with the increased surface and groundwater availability and concomitant private investments also substantially increased in the developed watersheds, resulting in the increased incomes as well as improved livelihoods (Sreedevi et al. 2006, 2008 and Pathak et al. 2007). Increased water availability also had a positive impact in improving welfare for the women, reduced drudgery, and protected the environment. In few well-managed watersheds, the productivity per unit of land and water increased substantially (Wani et al. 2003). However, agricultural production increased in many watersheds, the productivity per unit of land and water was not increased (Sreedevi et al. 2006). There is a need to adopt more water use efficiency measures along with integrated management of water resources in watersheds for sustaining the development measures. There are a number of examples where with the watershed development based on the over-exploitation of groundwater by the community, depleted groundwater to levels lower than those before the watershed development. Increased numbers of wells (open and bore wells) along with the increased number of pumping hours pose a serous threat for sustaining the development in the watersheds. The results from the watershed case studies from Andhra Pradesh, Madhya Pradesh, Rajasthan, Maharashtra and Gujarat are used to derive the conclusions (Batchelor C et al. 2000).

In the various watersheds of India like Lalatora in Madhya Pradesh, the treated area registered a groundwater level rise by 7.3 m. At Bundi in Rajasthan, the average rise was 5.7 m, and the irrigated area increased from 207 ha to 343 ha. In the Kothapally watershed, the groundwater level in open wells rose by 4.2 m. In the Rajasamadhiyala watershed, the number of open wells increased from 255 in 1995, with very poor yield with an average water column of 5.9 m to 308 wells with mean water column of 10.4 m. Overall, there has been an increase of 4.4 m of water column in 2004, as compared to that of 1995. The average pumping duration of 5.25 h per day in 1995 *increased to 10.4 h per day in 2004, resulting in increased irrigated area by 58 per cent. Similarly, the number of bore wells also increased from 102 to 200 during the period. Doubling of the number of the bore wells in the watershed is a cause of concern as in spite of farmers' experience of defunct bore wells in 1995 and earlier they have again drilled more bore wells than open wells. The marginal positive groundwater balance in lean and average rainfall years could tilt to negative side very soon if the farmers continued drilling bore wells and pumping at the rate they have done from 1995 to 1999. Although the villagers acted collectively for water harvesting, there is no concern or awareness amongst the villagers for a sustainable use of groundwater. There is a need for community monitoring of groundwater and its allocation to individuals. There is an urgent need to bring in the change in the attitude of all the stakeholders where most solutions for water management are thought from increasing water availability and not from demand management. Increased rainwater and groundwater use efficiency could maintain the incomes as well as sustain development; however, the groundwater management will need community participation, social and institutional mechanisms along with the enabling policy mechanisms through suitable incentive as well as punitive measures with legal support and execution. This paper discusses the results from on-farm community watersheds through groundwater management as the drivers for sustainable management of watersheds dry land areas. The issues of sustainable development and management of the groundwater resource through integrated watershed management (IWM) approach are also dealt relative to food production and security.*

1. Introduction

Access to reliable groundwater sources plays an important role in food security in many cases as the access to reliable sources of water reduces the production risk. Farm incomes at both micro (farm) and aggregate (regional) levels are buffered from the effects of precipitation variability, drought or general water scarcity conditions. As a result, access to reliable groundwater supplies can ensure the income flow needed to purchase food; and it plays a key role in food production. As a result, there can be a direct link between water access and its efficient use and food security. While access to water is important in many situations, in others irrigated agriculture is only one of many income sources or available livelihood strategies. Consequently, fast decline in groundwater levels, irrigation system deterioration, droughts and other direct indicators of water scarcity can serve as signals that food security may be threatened. Water scarcity measures are warning signals, but they do not on their own indicate the emergence of food insecurity (FAO, 2002)

Yields in groundwater-irrigated areas are higher (often double) compared to those in the canal-irrigated areas (Shah, 1993; Meinzen-Dick 1996). In India, the groundwater-irrigated area accounts for about 50 per cent of the total irrigated area and up to 80 per cent of the country's total agricultural production may, in one form or another, be dependent on groundwater (Dains and Pawar, 1987). However, the presence of groundwater irrigation alone cannot ensure increased yields as documented around the world. Groundwater availability needs to be seen as part of a complementary and mutually reinforcing set of other production technologies. Groundwater availability acts as a trigger to enable the farmers to invest in complementary inputs that, in combination, increase crop yields substantially. In the dry land SAT areas, an integrated watershed management resulted in increased groundwater availability that served as an entry point for increasing agricultural production and improving rural livelihoods (Wani et al. 2003, 2009).

Recent evaluations of the implications of water scarcity for food security range from the optimistic to the pessimistic. For example, Brown (1999) contends that primarily because of impending water shortages in northern China, the country will have to import up to 370 million tons of grain per year to feed its population in 2025. This massive increase in imports could cause steep increases in cereal prices and disruption of the world market (Seckler *et al.*, 1999). On the other hand, analyses by FAO and the International Food Policy Research Institute (IFPRI) indicate that yield increases (rather than increases in cultivated area) will be the dominant factor underlying the growth in cereal production in the coming decades and that, in aggregate, production increases will be sufficient to meet the demand (Rosegrant and Ringler, 1999; FAO, 2002a).

Food security is a function of three factors: availability; stability; and the ability of individuals to have access to food. As Sen (1999) and others (Dreze *et al*., 1995) have argued that during famines in India, starvation is frequently due to the inability of individuals to purchase supplies that are readily available in the market and is not a function of food availability per se. Sen's approach may have particular relevance for analysing the impact of emerging groundwater problems on food security. Studies made in the late 1980s highlighted the critical role that access to water, particularly groundwater, plays in poverty alleviation (Chambers *et al*., 1989). Reliable water supplies are a foundation that enables farmers to afford access to a wide range of development benefits (from food to education and health services) and can also enable farmers to diversify into other, often non-agricultural, income sources. These benefits are accessed through the improved yields enabled by the green revolution package of inputs. However, they carry a substantial risk because farmers must make investments in fertilizer, seed and other inputs in order to achieve them. These investments, which are often made through credit, will be lost if water supplies fail. Consequently, any decline in access to groundwater could have a major impact on the economic condition of small rural farmers.

The economic dimension is also central to understanding of the implications of groundwater over-extraction. Most discussions of groundwater over-abstraction emphasize the distinction between economic depletion (i.e. falling water levels make further extraction uneconomic) and the actual dewatering of an aquifer. Large-scale aquifers are depleted in an economic sense (the physical limits to pumping and associated energy costs) long before there is any real threat of physical depletion. Furthermore, wells owned by small farmers are generally shallow. In the context of poverty and famine, the falling groundwater tables will tend to exclude those farmers who cannot afford the cost of deepening wells long before they affect water availability for wealthy farmers and other affluent users (Moench, 1992). Consequently, substantial declines in water levels are particularly likely to have a major economic impact on farmers with limited land and other resources. This impact will tend to be particularly pronounced during the drought periods when a large numbers of small farmers could simultaneously lose access to groundwater as their wells dry up. A more creeping problem would occur during the non-drought periods as water-level declines undermined the economic position of small marginal farmers, forcing them onto already saturated unskilled agricultural and urban labour markets. The food security crisis in both these situations would be economic rather than related to food grain availability per se.

Groundwater, which is 38.5 % of the available water sources of the country, plays a major role in irrigation, rural and urban drinking water supply and industrial development. Groundwater meets nearly 55 % irrigation, 85 % of rural and 50 % of urban and industrial needs (Government of India, 2007). The use of groundwater in the agriculture sector has expanded rapidly because of the short gestation lags with which it can be developed, control over irrigation that it provides, free or subsidized availability of power in some states, water requirements for the crop production during critical growth stages caused due to erratic rainfall in dry land agriculture and paucity of surface irrigation.

The average annual rainfall in the country is 1170 mm, which correspond to an annual precipitation of 4000 billion cubic meters (BCM). Out of this volume of precipitation, 1869 BCM appears as average annual flow in rivers. Due to various constraints, only 1123 BCM is assessed as the average annual utilizable water (690 BCM from surface water and 433 BCM from groundwater). The present total water use is 643 BCM of which 83% is for irrigation. This is projected to grow to 813 BCM by 2010, 1093 BCM by 2025 and 1447 BCM 2050, against utilizable quantum of 1123 BCM. As regards to use, the extent of extraction has increased significantly over the years due to steep increase in the number of wells (tube and open wells). The average rate of increase in number of wells per year in India was 2.3%. The number of tube and open wells increased at the rate of 6.3% and 2.4% per year, respectively. It is estimated that currently there are 19 million wells in the country, out of which 16 million wells are in use and drawing about 213 BCM of water (Government of India, 2007).

According to the report on the 3rd Census of Minor Irrigation schemes (2005), the ultimate irrigation potential from groundwater source is 64.05 million ha, as compared to 46 million ha of land currently under groundwater irrigation. The report however, has revealed ~~a~~ further scope for developing groundwater in some area (such as the eastern and north-eastern part of the country), but in many states, the irrigation potential created has exceeded the ultimate potential, showing that mining of groundwater, that is exploitation beyond the present level of dynamic resource (Table 1). The over-exploitation of groundwater in ten years (1995-2004) increased by more than 4.5 times, making groundwater use a matter of serious concern. The over-exploitation of groundwater in six states (Gujarat, Haryana, Punjab, Rajasthan and Tamil Nadu) is 54% against a national average of 28%.

Table 1. Groundwater exploitation status in India (1995 and 2004).

Total number of assessment units (Blocks/Mandals/Taluks/Watersheds)	Year	Over-exploited	
		(No.)	(%)
7063	1995	428	6
5723	2004	1615	28

(Source: Ministry of Water Resources, 2005)

The prime cause of over-exploitation of groundwater is the rising demand from agriculture and rapid growth in urbanization and industrialization. In many groundwater irrigated areas, the decisions on cropping pattern and cropping intensity are being taken largely independent of the groundwater availability. Thus water intensive crops have tended to be grown in the face of scarcity of water. Such distortions occur partly due to the legal/regulatory regime governing groundwater (Aithal, 2007). In many states, groundwater extraction has exceeded annual recharge and water tables have gone down (Batchelor et al. 2000). Since groundwater is an open access resource, tragedy of commons occurs where everyone tries to extract as much as possible, leading to sharp degradation of the resource. There is an obvious urgency about managing groundwater in a sustainable way, which is an important driver for the sustainable development and management of productivity in dry land areas (Wani et al. 2005).

Over-exploitation of groundwater leads to: reduction in water yield in the wells, increase in pumping depth and cost of pumping, contamination of groundwater due to geogenic factors, resulting in increasing levels of fluoride, arsenic, iron and most importantly, in the failure of wells causing heavy economic losses to the farmers. The groundwater management rather than development is the major challenge facing the water resources, particularly in the dry land areas. Therefore, a focus on the development activities must be balanced by integrated management mechanism to achieve a sustainable utilization of groundwater resources, which is an important driver for the management of watersheds for sustainable development in the dry land areas.

2. Sustainable Groundwater Development and Management through IWM Approach

Groundwater is an invisible and endangered open or common access resource. Overexploitation of the groundwater beyond the sustainability limits in several parts of the country has resulted in widespread and progressive depletion of its levels in selected pockets of 370 (61%) out of 603 districts in the country (MOWR, 2005). In 15% of the blocks, the annual extraction of groundwater exceeds the annual recharge and in 4% of the blocks it is more than 90% of the recharge (CGWB, 2006). Reduction in groundwater supply, saline water encroachment, drying up of the springs and shallow aquifers, increased the cost of pumping by replacing centrifugal pumps with expensive submersible pumps, reduction in free flow, weakening drought protection and even local land subsidence in some places are threatening the sustainability of the aquifers. In many areas this has occurred more or less year-on-year, except for a temporary respite following years of exceptional monsoon rainfall when a partial recovery has been observed. The practice of the sale of water, either in cash or on crop sharing basis has also encouraged the rich farmers to construct deep tube-wells and over pumping the groundwater. Rapid decline in groundwater levels in the drier parts of India's a matter of concern, since demand-driven exploitation without regulatory measures and understanding of the area-specific problems lead to crisis not only for the present but may also result in damage to the groundwater system with adverse impact on the future water supply. It has been reported that the declining groundwater levels could reduce India's harvest by 25% or more (Singh and Singh, 2002). The other important part of the decline in the utility is related to the groundwater quality. The leachates from the compost pits, animal refuse, dumping grounds for garbage, synthetic fertilizers and pesticides enriched irrigation return flows, seepage from septic tanks, seepage of sewage have adversely affected the groundwater quality in several parts of India. Geogenic contaminants such as unsafe concentration of arsenic, fluoride and iron are related to excessive groundwater pumping. The depletion and degradation of groundwater is a major cause for increasing the rural poverty in India. Groundwater management deals with a complex interaction between human society and physical environment and presents a difficult problem of policy design. Aquifers are exploited by human decisions and overexploitation cannot always be defined in technical terms, but as a failure to design and implement adequate institutional arrangements to manage people who exploit the groundwater resource (Sharma, 2009).

Rainwater is the main source of water for agriculture but its current use efficiency for crop production ranges only between 30 – 45 %. Integrated Watershed Management (IWM) is the strategy adopted to enhance the water use efficiency for sustainable development of dry land areas. The IWM strategy demonstrated that dry land areas with good quality soils could support double cropping, while the surplus rainwater could recharge the groundwater. In IWM, the emphasis is on *in-situ* conservation of rainwater at the farm level with excess water taken out from the fields safely through community drainage channels and stored in suitable low-cost water harvesting structures (WHS). The stored water is used as surface irrigation or for recharging the groundwater. Main components of IWM in addition to rainwater conservation and harvesting include use of appropriate crops, improved crop varieties, cropping systems, and nutrient and pest management for increased productivity and water use efficiency (Wani et al. 2005).

Long-term on-station research at ICRISAT demonstrated that the Vertisols with a rainfall of 800 mm y^{-1} have the capacity to feed 21 persons per ha (producing food grains 5.1 t ha^{-1}) compared with current productivity of 1.1 t ha^{-1} supporting 4-6 persons per ha y^{-1}. This increased productivity is achieved with two fold increase in rainwater use efficiency from 30 % to 67 %, reduced soil loss by 75 %, and reduced runoff loss by 66% as compared to the traditional system of cultivation (Wani et al. 2003).

At the landscape level, community watershed management is used as a growth engine for sustainable development in dry land regions of Asia through management of rainwater efficiently for enhanced crop productivity on a sustainable basis through an innovative participatory IWM approach involving consortium and the convergence of several institutions, were implemented (Wani et al. 2003, 2007 and 2008a). This The participatory research and development approach at benchmark sites in several states/provinces in India, Thailand, Vietnam and China, representing different semi arid tropical agroecoregions has improved productivity (up to 250 %) and groundwater levels, while minimizing the degradation of the natural resources. 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 action. Capacity building engages in empowerment of the communities for sustainability (Wani et al. 2005 and 2006). This approach has vastly improved the livelihoods of 50,000 poor people in 368 watersheds across Asia.

Improving the availability of water (surface and groundwater) attributed to efficient management of rainwater and *in-situ* conservation (watershed-based efficient land management system, viz. contour cultivation, conservation furrows, broadbed and furrow system etc.) and establishing water harvesting and recharging structures especially low-cost structures (viz. percolation tanks, sunken pits, check dams, gabions and gully plugs etc.) through out the toposequence improved groundwater levels benefiting more number of small farmers (Fig. 1 and 2). *In-situ* water conservation measures were greatly helpful in reducing the pressure on groundwater extraction for crops by improving moisture regime in soils.

Figure 1. Runoff harvesting structures constructed in community watersheds in India.

Figure 2. A recharged open well with pump for irrigation at Shekta watershed, Maharashtra.

In the various watersheds in India such as Adarsha watershed in Kothapally, Andhra Pradesh, Bundi watershed in Rajasthan, and Laltora, Dewas and Madhusudhangadh watersheds in Madhya Pradesh, even after rainy season, the water levels in wells nearer to WHS sustained good groundwater yield (increase in quantity and duration) compared to those wells away from WHS (Fig. 3). In the Lalatora watershed in Madhya Pradesh, the groundwater level in treated area registered an average rise of 7.3

m, at Bundi watershed in Rajasthan 5.7 m increase was observed and at the Adarsha watershed, Kothapally in Andhra Pradesh 4.2 m rise in groundwater was recorded (Wani et al., 2003). The total recharge taking place through natural and water harvesting interventions is greatly affected by the amount of rainfall, its intensity, duration of the monsoon, ground and sub-surface characteristic (i.e. percolation rate and runoff coefficient). The various WHS resulted in the average contribution of seasonal rainfall during normal rainfall year to groundwater ranged from 27 to 34 per cent. (e.g. Adarsha watershed, Kothapally, AP was 27 %, Lalatora watershed was 29 % and Rajsamadhiayala watershed, Gujarat was 34 %) (Pathak et al. 2002 and Sreedevi et al. 2006).

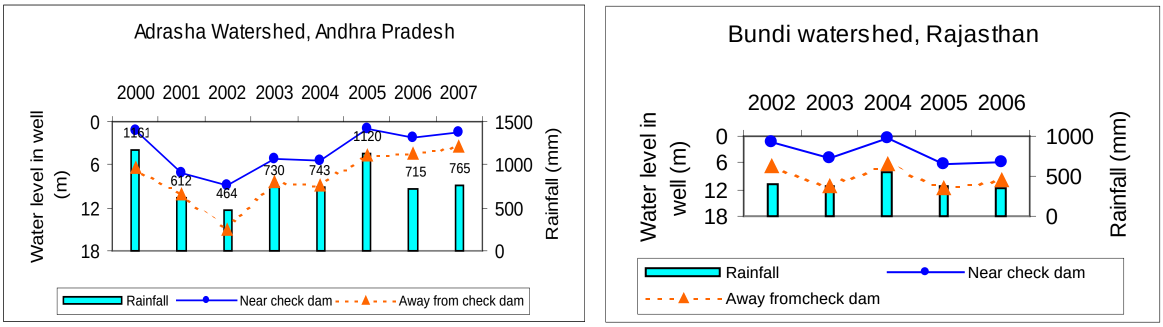

Figure 3. Mean annual groundwater levels in wells as influenced by the WHS at Kothapally and Bundi watersheds, India.

A detailed study of groundwater scenario in the Rajsamadhiayala watershed, Gujarat during pre- and post-watershed interventions revealed that the mean total groundwater recharge has increased by three folds in different rainfall situations and the water requirement has doubled after the watershed interventions due to increased cropped area, cropping intensity and change in the cropping pattern (Table 2) (Sreedevi et al. 2006). There existed as many as 255 open wells existed in 1995 with very less yield with an average water column of 5.9 m, but after 10 years (2004), there were 308 wells with mean water column of 10.4 m (Fig.4). The increase in water column during the *kharif* was 6.6 m, 5.3 m in the rabi, and 1.3 m in the summer. Overall, there was an increase of 4.4 m of water column in 2004 compared to that of 1995. This had a direct impact on the agricultural production and income, which have increased considerably. But productivity data suggests that there is still a good scope to increase the productivity per unit of water used by implementing appropriate water use efficiency measures.

Table 2. Pre- and Post-interventions scenario of total water requirement for crop irrigation and total groundwater recharge for good, average and lean rainfall years in Rajasamadhiyala watershed, Gujarat.

	Pre-intervention groundwater (GW) scenario (in MCM)			Post-intervention groundwater (GW) scenario (in MCM)		
Rainfall year	Total GW recharge	Total water requirement for irrigation	Net ground water balance	Total GW recharge	Total water requirement for irrigation	Net ground water balance
Good	1.40	1.08	0.32	4.03	2.31	1.69
Average	1.00	0.86	0.14	3.13	1.8	1.33
Lean	0.41	0.42	-0.01	1.07	0.95	0.12

Not only increase in the water column is observed, significant improvement in the water yield in wells were also reported as was evident by the duration of pumping hours per day for irrigation. The average pumping duration of 5.25 h per day in 1995 increased to 10.4 h per day in 2004, which means that there is a net increase of 5.2 h per day of pumping duration (Sreedevi et al, 2006).

Similarly in the Bundi watershed, Rajasthan, soil water conservation and rainwater harvesting interventions resulted in significant improvement in groundwater both in terms of duration of water available and the water yield from the wells. Before the watershed interventions, only 88 wells use to have water for 8 to 12 months in a year, whereas after the watershed interventions it increased to 187 wells (Fig. 5). Before watershed interventions, 52 wells out of 227 were functional only for 1-4 months mainly during the rainy season, where as after the watershed interventions particularly due to the construction of WHS, majority of the seasonally functional wells have become functional through out the year. Similarly, the mean depth of water column in the wells before the watershed interventions was 4.5 m, compared to 9.5 m after the interventions (Fig. 6).

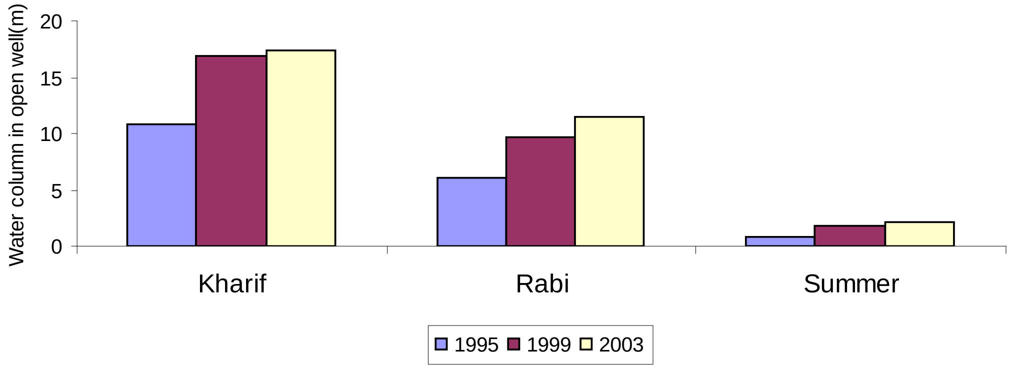

Figure 4. Average water column in open wells in Rajasamadhiyala Watershed, Gujarat,

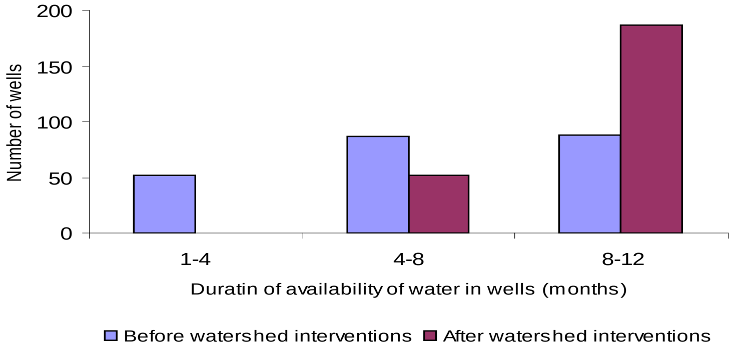

Figure 5. Effect of watershed intervention on duration of groundwater in Bundi watershed, Rajasthan (Source: Pathak et al. 2007)

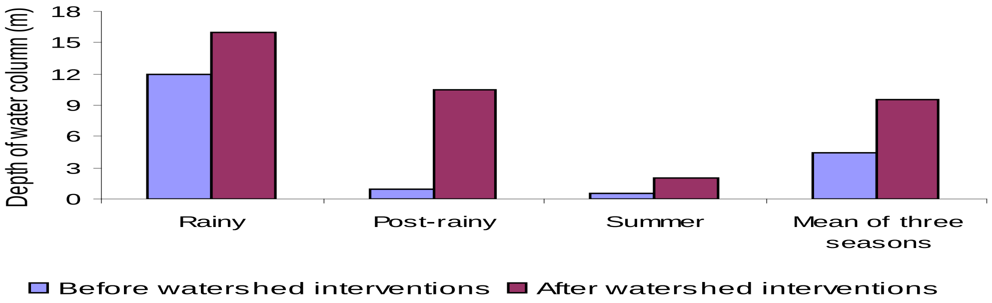

Figure 6. Effect of watershed intervention on water column in open wells, Bundi watershed, Rajasthan (Source: Pathak et al. 2007).

There is a substantial increase (more than 100%) in the mean depth of water column in the wells after the watershed interventions. Particularly during the post-rainy season, the depth of water column in the wells has increased substantially. There is a three-fold increase in the mean pumping duration, substantial improvement in the water recovery or recharge period and area irrigated by wells during post watershed interventions periods (Table 3).

Table 3. Number of total and active wells during the year in watershed before and after rainwater harvesting interventions

	Before Watershed Development				After Watershed Development			
	Total No. of wells	1-4	4-8	8-12	Total No. of wells	1-4	4-8	8-12
Rajasamadhiyala, Gujarat	255	120	77	18	308	12	88	208
Goverdhanpur-Gokulpur, Rajasthan	227	52	87	88	239	-	52	187
Shekta, Maharashtra	189 (133 functioning)	73	35	25	280 (271 functioning)	110	113	48

Overall, there is an increase of 48 % in the total number of wells and 51 % increase in the seasonally functional wells (1-4 months), while there is a drastic increase of 223 % wells functioning during 4-8 months in a year and 128 % increase was observed in perennially functioning wells (8-12 months in year). An average water column of wells through out the year was 1.02 m before the watershed intervention, whereas after the watershed interventions were implemented the water column in wells was 3.17 m, which shows an increase of about 211 % in the water column.

3. Impact of Groundwater Management on Crop Production and Food Security

In the Rajsamadhiayala watershed, Gujarat, the increased availability of water in the wells increased the area under irrigation significantly, particularly in the summer (Table 4). In the case of the Bundi watershed in Rajasthan, the area under irrigation increased by 66% after the implementation of the watershed program. Area under rainfed agriculture reduced due to increased availability of water in the watershed. This resulted in marked reduction in crop failures in the watershed area and increased farmers ‘confidence to invest in improved agricultural inputs. In addition, about 35 ha land was brought under horticulture with irrigation facility (Table 5).

Table 4. Area under irrigation (ha), 1995-2003, Rajsamadhiayala watershed, Gujarat

Cropping season	1995	1999	2003	% Increase in 2003 over 1995
Kharif	402	518	643	60
Rabi	356	469	551	55
Summer	11	18	24	118
Total	769	1005	1218	58

Table 5. The changes in land use pattern at Gokulpura-Goverdhanpura watershed, Bundi during 1997-2004.

Land use system	Area (ha)	
	Before watershed interventions (1997)	After watershed interventions (2004)
Irrigated	207 (15)*	343 (25)
Rainfed	327 (24)	209 (15)
Pasture	167 (12)	114 (8)
Horticulture	Nil	35 (3)
Forest	360 (27)	360 (27)
Dwelling and river	294 (22)	294 (22)
Total	1355	1355

* Values in parentheses are the percent of total area; Source: Pathak et al. 2007

The changing scenario in the land use pattern due to watershed development in the Shekta watershed clearly revealed a significant increase in the irrigated area (96 % for seasonally irrigated 88 % in perennial irrigated). There is also an increase in the area of pasture/grazing land. All cultivable fallow area was totally brought under cultivation (Table 6).

Table 6. Land Use Pattern in the Shekta watershed, Maharashtra.

	Area under different land use (ha)	
	Before watershed interventions (1998-99)	After watershed interventions (2004-05)
Rainfed	675.60	581.34
Seasonally Irrigated	94.51	185.24
Fully Irrigated	64.28	120.52
Pasture/ grazing	00.00	32.68
Cultivable wasteland	85.39	00.00
Govt. forest	132.60	132.60
Total	1052.38	1052.38

Source: Sreedevi et al.2008

4. Increased Farmers' Investment with Water Availability

The increased availability of water in wells encouraged farmers to invest more to acquire improved irrigation facilities. With increased groundwater availability, the private investments in farming increased (Table 7-9). The number of diesel engine pumps declined by 22 % over the period (1995 to 2003), while there was considerable increase by about 80 % in the electric motor pump sets in the Rajasamadhiyala Watershed. Farmers increased investments in irrigation equipments as was evident from 156 % growth in the number of farmers with the equipments, which helps in preventing the water loss through seepage and increases the irrigation efficiency (Table 7). There was a considerable increase in procurement of drip and sprinkler irrigation sets also.

Table 9. Effect of watershed program on irrigation equipments at the Gokulpura - Goverdhanpura watershed

	Before watershed interventions		After watershed interventions	
Irrigation equipment*	Number of equipments	Number of families	Number of equipments	Number of families
*Chadas (*traditional method)	164	221	110	151
Diesel pumps	79	145	139	202
Electric pumps	8	18	11	18
Pipeline length (m)	1685	50	5982	82

** Some of the equipments jointly owned by the families; Source: Pathak et al. 2007*

Table 7. Change in irrigation facility and equipments available in watershed (1995-2003), Rajasamadhiyala Watershed, Gujarat, India.

Irrigation facility/equipments	1995	1999	2003	Increase or decrease (%)
Diesel engine pumps	208	188	162	-22
Electric pump	205	281	368	80
No. of farmers procured pipeline	48	84	123	156
Drip irrigation set	16	22	38	138
Sprinkler irrigation set	1	2	4	300

Due to the increased availability of groundwater, total number of farmers having access to irrigation increased by 188 % from 1995 to 2003. There is a sharp increase in the number of small and marginal farmers who have access to irrigation compared to large farmers (172 %) increased by 292 and 317 percent, respectively (Table 8) (Sreedevi et al. 2006).

Table 8. Change in the number of farmers having access to irrigation, Rajsamadhiayala watershed, Gujarat.

Farmers category	1995	1999	2003	Increase in 2003 over 1995 (%)
Small	25	82	98	292
Marginal	16	28	35	317
Large	32	65	87	172
Total	73	175	210	188

Post-project scenario revealed about 76% increase in the number of diesel pump sets and 38% increase in the electric pump sets for lifting irrigation water along with the increase in the pipeline to save water from seepage loss (Table 9) in the Gokulpura Watershed in Rajasthan (Pathak et al. 2007)

5. Increased Crop Productivity and Food Security

Increase in crop productivity is common in all watersheds due to watershed interventions in a short span of time. In the Adarsha watershed, Kothapally, Andhra Pradesh, integrated watershed management technologies increased maize yield by 2.5 times and sorghum yield by 3 times. Overall, in the 65 community watersheds, implementing best-bet practices resulted in significant yield advantages in sorghum (35-270 %), maize (30-174 %), pearl millet (72-242 %), groundnut (28-179 %), sole pigeon pea (97-204 %), and intercropped pigeonpea (40-110 %). The results in Figure 7 show a similar trend in the Bundi watershed, Rajasthan. In the Adarsha watershed, Kothapally, Andhra Pradesh, (Wani et al. 2006, 2009) due to additional groundwater recharge, a total of 200 ha were irrigated in the post-*kharif* season and 100 ha in post-*rabi* season, mostly to vegetables and flowers.

Integrated watershed management through primarily water (surface and groundwater) conservation and management compounded with other improved practices have shown a significant increase in productivity, cropping intensity and income, while controlling degradation of natural resources (Table 10). Compound growth rate (CGR) of productivity, net returns and benefit cost (B:C) ratio are mean of selected major crops. In the case of Kothapally watershed, the increase in cropping intensity, B:C ratio and per capita income ranged 30-55 %, 45-88% and 19-78 % respectively in community watershed after the implementation of watershed interventions over the baseline data.

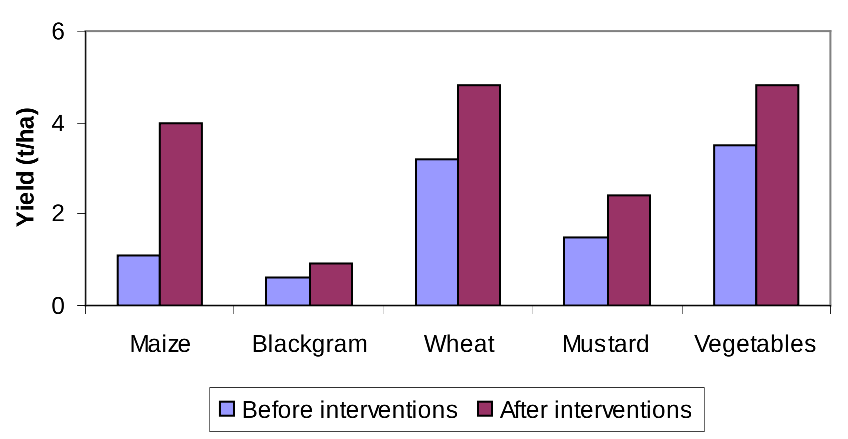

Figure 7. Crop productivity before and after interventions at Bundi watershed, Rajasthan.

Table 10. Growth rate of productivity, net return, increase in cropping intensity, B:C ratio and per capita income due watershed interventions from community watersheds in India.

Watershed	Compound growth rate		Increase in Cropping intensity (%)	Increase in B:C ratio (%)	Increase in per capita income per year(%)
	Productivity	Net returns			
Kothapally, Andhra Pradesh * (1999-2006)	101%	34%	30	88	78
Bundi, Rajasthan (1997-2004)	6.5 – 14.3	7.9 – 36.3	55	45	28
Rajsamadhiayala, Gujarat (1995-2003)	4.6 – 9.1	8.7 – 21.6	44	55	39
Shekta, Maharashtra (1999-2005)	2.2 – 16.6	4.5 – 22.7	30	47	19

** productivity and net returns are the percent increase after intervention over the base line data*

Food Security is a state of assuring the physical availability and economic accessibility to enough food (in an environmentally and socially sustainable manner) in terms of quantity (safe, nutritious, balanced), quality (amount, distribution, calories) and cultural acceptability for all people at all times for a healthy and active life.

The various measures implemented through the integrated watershed management program, particularly improving the sustainability of groundwater source, have improved the food, fodder and fuel security over a period of time (Fig. 17). The results in Table 11 reveal the availability and requirement of food per capita per month in monitory value to measure the food gap as well as security in the Rajasamadhiayala watershed in Gujarat. In 1995, per capita food secured was only 20 percent against requirement, while the food security increased drastically by 71 % in 1999, where as in 2003-04, the total per capita food security was attained (109 %) owing to the overall development activities of the watershed programs in general, particularly due to additional water availability through rainwater harvesting and groundwater recharging structures (Sreedevi et al. 2006).

Table 11. Food security over period of Time in Rajasamadhiyala Watershed

	Unit	1995	1999	2003
Total Population	No	1631	1691	1747
Land Availability per capita	ha	0.446	0.442	0.437
Land value	Rs. 100000	0.558	1.336	1.747
Income from all sources				
Interest on land	Rs. 100000	0.0335	0.0802	0.1048
Crops	Rs. 100000	18.75	169.69	306.57
Animal husbandry	Rs. 100000	11.41	11.26	11.6
Other Income (services/employment)		0.78	1.02	1.45
Total Income		30.97	182.05	319.72
Income per capita	Rs.100000 per month	0.019	0.108	0.183
Income Availability	Rs. per month	437.05	1564.91	2398.11
Income Requirement	Rs. per month	2200.00	2200.00	2200.00
Food Gap Rs.(Required-Availability)*		-1762.95	-635.10	198.11
Food security per capita per month (%)		19.866	71.132	109.005

* Rs 2200 per capita per month are calculated based on the defined of World Food Summit, 1996, Rome, to measure food security (availability, acceptability and utilization).

In the case of fodder security, only 61 per cent was secured in 1995, while in 1999, it was fully secured (103 %) within a short span of time (Table 12). The fuel security also improved in 1999 (138 %) compared to 1995 (Table 13).

The science-led participatory watershed development and management through consortium and convergence approach enhanced the agricultural productivity, food security and incomes, decreased poverty of rural poor, reduced labor migration and improved environmental quality.

Table 12. Fodder security over period of time in Rajasamadhiyala.

	Unit	1995	1999	2003
Total animal	No	1743	1526	1235
Total area	Ha	1075	1075	1075
Area under fodder	Ha	404	381	501
Area under fodder (%)		37.58	35.44	46.60
Fodder productivity	kg ha^{-1}	5739	7979	7590.5
Fodder production	kg year^{-1}	2318556	3039999	3802840.5
Fodder from by-product	kg year^{-1}	1456805	1967169	2296282.5
Total fodder availability kg year^{-1}		3775361	5007168	6099123
Fodder requirement	kg year^{-1}	6175251	4879453	5597122
Fodder insecurity	kg year^{-1}	-2399890	127715	502001
Fodder insecurity	kg year $^{-1}$ animal^{-1}	-1376.87	83.69	406.48
Fodder security per animal per annum (%)		61.14	102.62	108.97

Table 13.Temporal change in fuel security in Rajasamadhiyala.

	Unit	1995	1999	2003
Total Population	No	1631	1691	1747
Total Area	Ha	1075	1075	1075
Area under fuel	Ha	335	411	395
Area under fuel (%)		31.16	38.23	36.74
Production of cotton residue for fuel	kg year^{-1}	565251	720722	697453
Production of others fuel	kg year^{-1}	14822	15382	16123
Total Production	kg year^{-1}	580073	736104	713576
Fuel requirement	kg year^{-1}	473043	534364	627432
Fuel requirement	kg year^{-1} person^{-1}	290.03	316.00	359.15
Insecurity of fuel	kg year^{-1}	107030	201740	86144
Fuel security per capita/ year (%)		122.63	137.75	113.73

6. Conclusions

Groundwater development in the country has expanded extensively. Over-exploitation of the resource in most parts of the country has led to a rapid decline in the groundwater table. This has threatened not only the food security and environment, but also the sustainable development. Further depletion of groundwater resource has been affecting the small and marginal farmers the most, threatening their livelihood in many cases. The sustainability of groundwater use is one of the core areas, which requires major attention for meeting the water requirement and ensuring food security. An important way of addressing the issue is by augmenting the groundwater supplies in the shallow aquifers on micro watershed basis through groundwater recharging and rainwater harvesting system. Our experience from community watersheds showed that recharging can be made much more effective by the use of scientific inputs and analysis than otherwise. It may however be noted that even if the entire potential of recharge is utilized, shortage will still persist, underscoring the need of improving water use efficiency and limiting extraction of groundwater. In limiting the extraction, probably the legal regime alone would not meet the goal but participatory management of water resources ensuring equity along with enabling policies to incentivize promotion of water efficient technologies and crops along with punitive measures are needed. While the measures suggested in the National Water Policy to promote sustainability of groundwater should be the cornerstone in the groundwater development and regulation strategy in the country (Government of India, 2007).

Sustainable groundwater development and management in the overexploited regions needs to be taken up by incorporating artificial recharge to groundwater from in-situ and ex-situ rainwater harvesting through integrated watershed interventions, management of salinity ingress in coastal aquifers, conjunctive use of surface- and groundwater, management of poor/marginal quality groundwater, water conservation by increasing water-use efficiency, regulation of groundwater development and extraction, etc. Several studies conducted in the community watersheds through integrated watershed management approach have concluded that these technologies have been successful in the sustainable development; and the management of groundwater resource would be the key to achieve breakthrough in agricultural production and food security.

Access to groundwater can be a major engine for food security, poverty alleviation and economic development in the rural areas. The effective management and utilization of groundwater not only as a source of water for agriculture and other consumptive purposes, but also as a supplementary source of surface water flows, wetlands and wildlife habitats calls for an increased attention to the two major and interdependent source of concern: depletion and pollution. Therefore, the focus on the development activities must be balanced by management mechanisms, enabling policy and institutional mechanisms to achieve a sustainable utilization of groundwater resources. The groundwater management rather than development is the major challenge facing the organizations/institutions dealing with water resources.

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