Research Report IDC-7

ICRISAT Development Center

PMO Strategy Document Series

Pradhan Mantri Krishi Sinchai Yojana:
Enhancing Impact through Demand Driven Innovations

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

ICRISAT DEVELOPMENT CENTER

Citation: Wani SP, Anantha KH, Garg KK, Joshi PK, Sohani G, Mishra PK and Palanisami K. 2016. Pradhan Mantri Krishi Sinchai Yojana: Enhancing the Impact through Demand Driven Innovations. Research Report IDC-7. Patancheru 502 324. Telangana, India: International Crops Research Institute for the Semi-Arid Tropics. 52 pp.

Acknowledgement

We are extremely thankful to the Prime Minister's Office for asking us to help prepare the strategy report on Pradhan Mantri Krishi Sinchai Yojana: Enhancing the Impact through Demand Driven Innovations. We sincerely acknowledge the support of the Task force members for their contributions towards the report and the case studies. We thank all the officials of the Department of Agriculture, Secretaries, Additional Secretaries, Joint Secretaries, partners and donors for the report and the case studies. We also thank all the officers of the Ministry of Agriculture and Farmers Welfare, Government of India for their very useful suggestions to help prepare the report.

This report is part of a series of Strategy Papers drafted on the request of the Prime Minister's Office, India. The other reports in this series include:

- Mission India for Transforming Agriculture (MITrA)
- Transforming Agricultural Marketing in India: Linking Farmers to a National Gateway and E-Markets, Current Scenario and a Way Forward;
- Soil Health Mapping and Direct Benefit Transfer of Fertilizer Subsidy;
- Transforming Weather Index-Based Crop Insurance in India: Protecting Small Farmers from Distress, Status and a Way Forward;
- Digital Agriculture; and
- Self-sufficiency in Pulse Production.

Cover page photos: *ICRISAT*

Pradhan Mantri Krishi Sinchai Yojana: Enhancing the Impact through Demand Driven Innovations

Suhas P Wani, KH Anantha, Kaushal K Garg, PK Joshi, Girish Sohani, PK Mishra and K Palanisami

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

ICRISAT DEVELOPMENT CENTER

About the authors

Lead authors

Suhas P Wani	Research Program Director – Asia and Director, ICRISAT Development Center, ICRISAT
KH Anantha	Senior Scientist (Natural resource management), ICRISAT Development Center, Research Program-Asia, ICRISAT
Kaushal K Garg	Senior Scientist (Natural resource management), ICRISAT Development Center, Research Program-Asia, ICRISAT
PK Joshi	Director, South Asia, International Food Policy research Institute (IFPRI), NASC Complex CG Block, Dev Prakash Shastri Road, Pusa, New Delhi 110012
Girish Sohani	President and Managing Trustee of BAIF Development Research Foundation, Pune.
PK Mishra	Director, ICAR-Indian Institute of Soil & Water Conservation, 218 Kaulagarh Road, Dehradun, Uttarakhand-248195
K Palanisami	Consultant, IWMI, Coimbatore

Contributing authors

Ajit Jain	Jt. Managing Director, Jain Irrigation Systems Ltd., Maharashtra
Amita Prasad	Joint Secretary, Ministry of Water Resources, New Delhi
R Anand Kumar	Executive Director, TWDA, Govt. of Tamil Nadu, Chennai
Anita Ramachandran	Commissioner, Rural Development, Govt. of Telangana, Hyderabad
Anurag Bhardawaj	Director, Watershed Development Department, Govt. of Rajasthan, Jaipur
Arvind G. Risbud	Executive Director, MYRADA, Bengaluru
Avinash Tyagi	Secretary General, International Commission on Irrigation and Drainage (ICID), New Delhi
Bhatt RK	Director I/C, CAZRI, Jodhpur
Biswanath Sinha	Associate Director, Sir Dorabji Tata Trust, Mumbai
Chandra A Madramootoo	Chair, ICRISAT Governing Board James McGill Professor and Dean, McGill University, Canada
Girish Sohani	President, BAIF Development Research Foundation, Pune
C Nagarani	Addl. Commissioner (IWMP), Rural Development, Govt. of Andhra Pradesh, Hyderabad
B Nijalingappa	CEO, SLNA, Jharkhand
Nikhilesh Jha	Mission Director (NWM), Ministry of Water Resources, New Delhi
Pradeep Kumar,	Commissioner (SPR), Ministry of Water Resources, New Delhi
HG Shivananda Murthy	Commissioner, Watershed Development Department, Govt. of Karnataka, Bengaluru
Sandeep Dave	Joint Secretary, Department of Land Resources, New Delhi
Ch Srinivsa Rao,	Director, CRIDA, Hyderabad
SK Srivastava	Chief Engineer, NWA, Ministry of Water Resources, New Delhi
Vishwa Mohan Upadhyaya	Commissioner, Panchayat & Rural Development Department, Govt. of Madhya Pradesh, Bhopal

Contents

1. Executive Summary

The Ministry of Agriculture and Farmers Welfare, Government of India, has launched the Pradhan Mantri Krishi Sinchai Yojana (PMKSY) to address India's key agricultural challenges in the 21st century i.e., to reduce poverty and ensure food security for the growing population in the face of climate change, scarce and limited water and land resources. This initiative proposes to provide irrigation to every farm in the country (*Har Khet Ko Pani*) and improve water use efficiency (Per Drop More Crop and Income). It aims to bring together various schemes and programs for water harvesting, conservation and efficient management in order to ensure there is enough water for agriculture. This program also aims to harness the potential of agriculture by effectively utilizing green (soil moisture) and blue water (irrigation) for improving efficiency, sustainability, equity and resilience at the farm level, especially in rainfed, marginal and fragile areas, using an integrated approach.

- All the four components of the PMKSY namely, Accelerated Irrigation Benefits Programme, Per Drop More Crop and Income, *Har Khet Ko Pani* and Integrated Watershed Management Programme (IWMP) need to be implemented in a coordinated and transparent manner by adopting a micro-watershed as a unit and integrate meso- and macro- watersheds at a basin level.
- The PMKSY when implemented fully in 10 years, can add a total value of ₹ 23 lakh crore[1] to the gross domestic product (GDP), assuming that an investment of ₹ 251,665 crore is made by the central and state governments in the form of incentives. The total cost including farmers‘ contribution would be ₹ 466,850 crore, with farmers' share of 10 % in watersheds and 50 % in other interventions. In addition, for implementation of the scheme, a 10 % additional resource would be needed for capacity building, monitoring and plan preparations as well as for establishing the "sites of learning".
- Accelerated irrigation benefits under the PMKSY can be achieved by reducing the transmission losses and adopting the goal of 'zero flood irrigation by 2020' and popularizing micro-irrigation (MI) systems with need-based irrigation scheduling for the crops rather than calendar-based irrigation.
- However, maximum benefit of ₹ 17.54 lakh crore is expected from Integrated Watershed Management Programme and *Har Khet Ko Pani* interventions in rainfed areas and ₹ 5.58 lakh crore from the cultivable command area (CCA) as well as groundwater irrigated areas.
- The benefit-cost ratio (BCR) for the PMKSY at macro level would be about 9.2:1. For individual farmers', the benefit would vary from ₹ 3,000 to 150,000 ha^{-1} yr^{-1} with different technologies. Higher returns are expected in rainfed areas with BCR at 9.6:1 compared to the returns from irrigated areas with BCR at 8.2:1.
- More resources/investments are needed to make agriculture, in vulnerable rainfed areas, drought proof and climate resilient. Private investments could be channelized to develop rainfed areas in the country for cultivation of high-value crops, through protected cultivation, under *Har Khet Ko Pani* and watershed programs.
- Integrated watershed development, *Har Khet Ko Pani*, Per Drop More Crop and income programs, are critical in transforming rainfed agriculture and also in facilitating adoption of diversified livelihood options among smallholder farmers, women and youth.
- However, a 'business as usual' approach will not deliver results. For realizing the full benefits of the PMKSY, it needs to be implemented in a mission mode, led by the Director General at the national level for effective convergence of programs and practices in an integrated way for benefit of smallholder farmers, who are marginalized, and socially and economically backward. All resources of the PMKSY need to be vested with the Director General of the PMKSY and annual allocations for the component implementation can be disbursed to the implementing department/ministry which is assigned the responsibility. This would ensure accountability and maximize impact of the PMKSY.
- A three-tier structure at national, state and district level is proposed for effective planning, implementation, monitoring and achieving the impact in a coordinated manner. Nodal agency at each level to be supported by the Advisory Board consisting of renowned subject experts, secretaries of all the concerned departments, financial institutions like NABARD and NGO representatives.

1. 1 lakh = 10^5 and crore = 10^7 (10 million)

- Agroecological zone-wise crop planning is another important intervention for improving water use efficiency in the country. This can be implemented through innovative incentives, market support and penalties such as no market support, no fertilizer and seeds subsidy, for the non-adopters.
- Groundwater recharging through aquifer mapping, aquifer recharging and rainwater harvesting needs to be pursued vigorously in most parts of the country. Enabling policies (for e.g., use of drones for digital imageries, incentives for using organic manures, warehousing and marketing support, etc.) and institutions for sustainable management of groundwater need to be developed urgently. Good practices like participatory groundwater management and sharing of borewells by the community need to be scaled up. It is proven that community participation is important to promote demand-driven interventions for ensuring success rather than target-based supply-driven interventions.
- New science tools like remote sensing, geographic information system (GIS), water budgeting, simulation models and information and communications technology (ICT) among others need to be fully integrated and their use made compulsory for effective planning, monitoring and ensuring transparency. Public private partnership (PPP) models can be used to harness these latest technologies for the benefit of smallholder farmers.
- Capacity building is a critical part for the successful implementation and existing institutions like Water and Land Management Training and Research Institute (WALMTARI), National Institute of Rural Development (NIRD), state universities, national research institutions and good NGOs can be strengthened. Services of international institutes like ICRISAT can be harnessed effectively.
- Specific regions/areas which are more vulnerable to droughts (for e.g., Vidarbha and Marathwada in Maharashtra, Bundelkhand region in Madhya Pradesh and Uttar Pradesh, rainshadow regions in Karnataka, Rayalaseema region in Andhra Pradesh and drought prone districts in Gujarat, Rajasthan, Telangana and other states), climate change impacts, flooding, poor groundwater quality (arsenic, fluorides or nitrate affected areas) should get higher resources (technical, financial as well as human) for helping the communities.
- Productivity of rainfed agriculture (76 million ha) can be doubled by adopting science-led interventions, improving knowledge delivery systems using ICT, skill development for building the capacity of all stakeholders by adopting value-chain approach through consortium, convergence, collective action and training. This would contribute significantly for improving the livelihoods as well as food and nutritional security.
- Groundwater recharging through aquifer mapping, aquifer recharging and rainwater harvesting needs to be pursued vigorously in most parts of the country.
- Enhancing water use efficiency (WUE) through conjunctive use of green and blue water efficiently, while growing high-value crops in protected cultivation, as well as by bringing in rainy season fallows (2 million ha) and rice fallows (11.6 million ha) under cultivation, using improved land, water, crop management practices will be effective.

2. Background and Rationale

India with a population of 1.28 billion, faces the challenging task of almost doubling food production from the declining per capita availability of land and water. Nearly 55 % of the population in India is dependent on agriculture and allied sectors for their livelihoods; and agriculture contributes only around 14 % to the nation's GDP (GoI 2014). Indian agriculture is essentially small farm agriculture with majority of farmers owning less than 1 ha of land; and 83 % of farmers representing small farming households (GoI 2014). In India, per capita water availability has declined from 5,177 m^3 in 1951 to 1,545 m^3 in 2011 due to rise in population from 361 million in 1951 to 1.21 billion in 2011 (GoI 2014). The total cultivable land in India is 141 million ha with a cropping intensity of 135%. Groundwater and surface water sources irrigate about 44 and 21 million ha of agricultural lands, respectively (nearly 46 % of total cultivable land), and rest of the cultivable area (76 million ha) is rainfed. Indian agriculture faces some critical challenges:

Poor performance of irrigation projects: Since Independence, the Government of India (GoI) has made huge investments in development of water resources. The performance of public funded irrigation projects has been continually declining over the years due to system maintenance issues, inefficient delivery systems, as well as inefficient management at field level. Further, the expansion of irrigated area does not commensurate with the amount of capital invested. Despite huge investments (approx. US$60 billion), the area under irrigation has not increased and at the same time, yields are stagnating (Shah 2011).

The storage capacity of most of the large and medium capacity reservoirs has declined (both live and dead storage capacity) by 20-30 % over the years, due to excessive siltation leading to less water storage and availability.

Although large-scale surface irrigation projects have harvested substantial amount of water (300 billion cubic meter per year), which is almost equal to the groundwater withdrawal, the cultivated acreage using surface water sources is almost half, when compared to that using groundwater sources. This indicates indiscriminate use of water and low water use efficiency. Further, increased cost of cultivation and soil salinity results in unsustainable agriculture in such irrigated areas.

Over exploitation of groundwater: The Green Revolution during the 1970s along with advanced technology of water pumping made a significant impact on groundwater use. Individual farmers made huge private investments for developing and using groundwater resources, significantly enhancing the irrigated areas. Innovations in pumping technology along with free or subsidized power supply has accelerated groundwater extraction, resulting in overexploitation and declining groundwater resources to unsustainable levels in many parts of the country. Public investments in canal irrigation projects were concentrated in pockets, leaving the rest of the regions under rainfed farming and it is here that groundwater played a significant role in meeting the demands. Groundwater is a major source of water in rainfed systems (62 % of irrigated area) and this resource is unsustainably overexploited. It is estimated that out of the 5,842 assessment units, 802 units have been categorized as overexploited, 169 as critical and 523 units as semi-critical (GoI 2013). About 58 % of replenishable groundwater in the country is already being exploited through tube wells and dug wells.

Even in irrigated areas, there is huge disparity in water access and utilization among end users, which has resulted in groundwater overexploitation, thus lowering the groundwater table in canal irrigated areas as well. In irrigated areas, farmers have switched over to economically remunerative crops that require intensive cultivation and more water.

The number of borewells increased from less than one million in the 1960s to 20 million by 2009 (Dewandel et al. 2010). As a result, groundwater withdrawals escalated from less than 25 km^3 (km^3 = billion cubic meter, in the 1960s to 250-300 km^3 in 2008 which is several times higher than the withdrawals by any other developed and developing country (Shah 2009).

The latest reports from the GRACE Mission of NASA (Rodell et al. 2010) showed continued groundwater decline of 4.0 ± 1.0 cm yr^{-1}, equivalent height of water (17.7645 $km^3 yr^{-1}$) over the Indian states of Rajasthan, Punjab, Haryana and Delhi. During the study period from August 2002 to October 2008, the groundwater depletion was equivalent to a net loss of 109 km^3 of water in northwest India. Such high rates of groundwater exploitation have increased the percentage of 'unsafe' districts from 9 % to 30 % in a span of nine years between 1995 and 2004 (Vijay Shankar and Kulkarni 2011), thereby reducing well-being, particularly that of the poorest members of society (Anantha 2013).

Breakdown of institutional mechanisms to manage water harvesting structures: In the past, communities developed and managed water harvesting structures such as tanks in southern India, *havelis* in Bundelkhand, *khadins* in Rajasthan, jalmandhir in Gujarat, gul in Uttarakhand, kuhl in Himachal Pradesh, phad in Vidarbha in Maharashtra, goonchi in Ananthapur in Andhra Pradesh, ahar-pyne in southern Bihar and northern Jharkhand, zebo in Nagaland, dong/jaan in lower Assam, etc. These water harvesting structures contributed in terms of water supply for domestic and agricultural usage. However, due to breakdown of institutional mechanisms, poor maintenance, siltation, change in land-use practices and reduced inflows, these structures have become non-operational over the years.

Declining resource use efficiency: Farm productivity and resource use efficiency in both irrigated and rainfed systems are declining over the years, due to inappropriate water and land management practices, water scarcity, land degradation, land fragmentation, lack of access to credit and markets, etc. Further, due to the climate change, water uncertainty is increasing and has led to the vulnerability of food production in tropical countries like India (Boomiraj et al. 2010; Rao et al. 2013). Future of food security largely depends on the rainfed systems, as currently, farmers' yields are lower by two to five folds than the achievable potential yields (Rockström et al. 2007; Wani et al. 2009).

Underutilized potential of micro-irrigation: For enhancing water use efficiency and minimizing unproductive evaporative loss of water, the government has promoted micro-irrigation systems using sprinklers and drip, as key demand management interventions for conserving water. Properly designed and managed micro-irrigation systems can save up to 40 to 80 % of water, through increased water use efficiency of up to 100 % when compared to a mere 30-40 % under the conventional surface irrigation system (Palanisami et al. 2011).

In India, total potential area coverage under micro-irrigation is about 42 million ha through groundwater resources (Palanisami et al. 2011). Out of this, about 30 million ha area is suitable for sprinkler irrigation for crops like cereals, pulses, and oilseeds in addition to fodder crops. This is followed by drip irrigation with a potential of around 12 million ha under cotton, sugarcane, fruits and vegetables, spices and condiments, some pulse crops like pigeonpea, etc. However, compared to the potential of 42 million ha, only 3.87 million ha (1.42 million ha under drip and 2.44 million ha under sprinkler) was under micro-irrigation as of 2011 which is about 9.16 % of the total potential area.

Only a few states like Andhra Pradesh, Maharashtra and Tamil Nadu have adopted significant areas under micro-irrigation. The poor adoption is attributed to a number of factors, such as, high cost, complexity of the technology and other socio-economic issues, such as, lack of access to credit facilities, fragmented landholdings, localized crop pattern, etc. Further, faulty design of irrigation system is another important factor forcing poor adoption of micro-irrigation, especially among the small and marginal farmers. For e.g., a farmer who owns a high discharge capacity pumpset, can irrigate more area potentially. In some parts of Tamil Nadu, farmers were ignorant about the maintenance package to be adopted for drip systems, which acted as a constraint for its adoption (Palanisami et al. 2011). High costs of soluble fertilizers also restricted the use of efficient fertigation practices.

Use of untreated domestic wastewater: With increasing water scarcity, farmers in rural and peri-urban areas are using untreated domestic wastewater for agriculture, thus increasing the risk of nitrate pollution as well as health hazards for agricultural workers and consumers. For example, approximately 16,000 ha of land in and downstream of Hyderabad, along the 10 km stretch of the Musi River (Krishna river basin, southern India) is irrigated with wastewater or a combination of wastewater and groundwater (Buechler and Devi 2005). However, such practices pose risks to human health and the environment (Buechler and Scott 2006).

To address the issue of sustainability of food production, in an environment friendly way, important matters in irrigated agriculture need urgent attention. This is possible only by enhancing the efficiency of irrigation schemes, minimizing transmission losses, minimizing land degradation (salinization, waterlogging and pollution of groundwater and environment), controlling overexploitation of groundwater and increasing agricultural productivity as well as profitability. To overcome labor scarcity, cooperative farming can be encouraged, by involving Self-Help Groups (SHGs) and production groups like Farmer Producer Organizations (FPOs) along with mechanization of agricultural operations.

To address these water scarcity issues, the GoI has taken the initiative to adopt Integrated Water Resource Management framework and ensure efficient use of water through PMKSY. Through convergence of irrigation schemes, the efficiency and sustainability issues are addressed with enabling policies and institutions at the local and national level. The Accelerated Irrigation Benefits Programme, Per Drop More Crop and Income, Integrated Watershed Management Programme and *Har Khet Ko Pani* are unique initiatives to address management of green and blue water collectively for addressing the Sustainable

Development Goals (SDGs). In this report, we discuss the opportunities and strategies to harness the potential of rainfed and irrigated systems by implementing a holistic and integrated water management approach.

3. Experiences and Learning

3.1 Rainfed agriculture – experience of ICRISAT with watershed programs

Rainfed agriculture covers a continuum of agriculture and comprises of areas that are completely dependent on rain and areas with supplemental irrigation through rainwater harvesting or groundwater recharge (Molden et al. 2007; Rockström et al. 2007). Globally, rainfed agriculture covers 80 % of agriculture and varies across regions (60 % in Asia and 97 % in Africa). In India, 76 million ha (56 % of arable land) of rainfed areas in the country, supports 40 % of human population, 78 % of cattle, 64 % of sheep and 75 % of goat population. Rainfed agriculture has a large share of crop area under rice (42 %), pulses (77 %), oilseeds (66 %) and nutritious cereals (85 %). As estimated by the Technical Committee on Watershed Development (2006), even in the best possible scenario of irrigation development, about 40 % of the additional food grains supply needed to match the future rise in demand, will have to be generated from rainfed agriculture in India. In a country like India, with an average rainfall of 1,100 mm yr^{-1}, there exists a problem of physical water scarcity in rainfed areas which can be counted as prime areas in terms of low agricultural productivity (1 to 1.5 tons ha^{-1}), poverty, food insecurity, and malnutrition. Further, rainfed agriculture is prone to severe land degradation and is vulnerable to adverse climate change impacts.

Rainfed agriculture is referred to as 'one ton agriculture'. However, long-term research at ICRISAT-India and other research institutions in Asia and Africa have shown that current crop yields are lower by two to five folds (Wani et al. 2003, 2008; Rockström et al. 2007). A long-term study at ICRISAT demonstrated that yields from rainfed system can be as high as 5.2 ton ha^{-1} yr^{-1}, supporting 27 persons ha^{-1} yr^{-1}, compared with 1.1 ton ha^{-1} yr^{-1} supporting only 6 persons ha^{-1} yr^{-1}, as in traditional systems, managed through conventional farmers' practices (Figure 1). Such high and sustainable production was achieved without supplemental irrigation. Nevertheless, it was inferred that utilizing supplemental irrigation using harvested rainwater could further result in increased yields, cropping intensity and income.

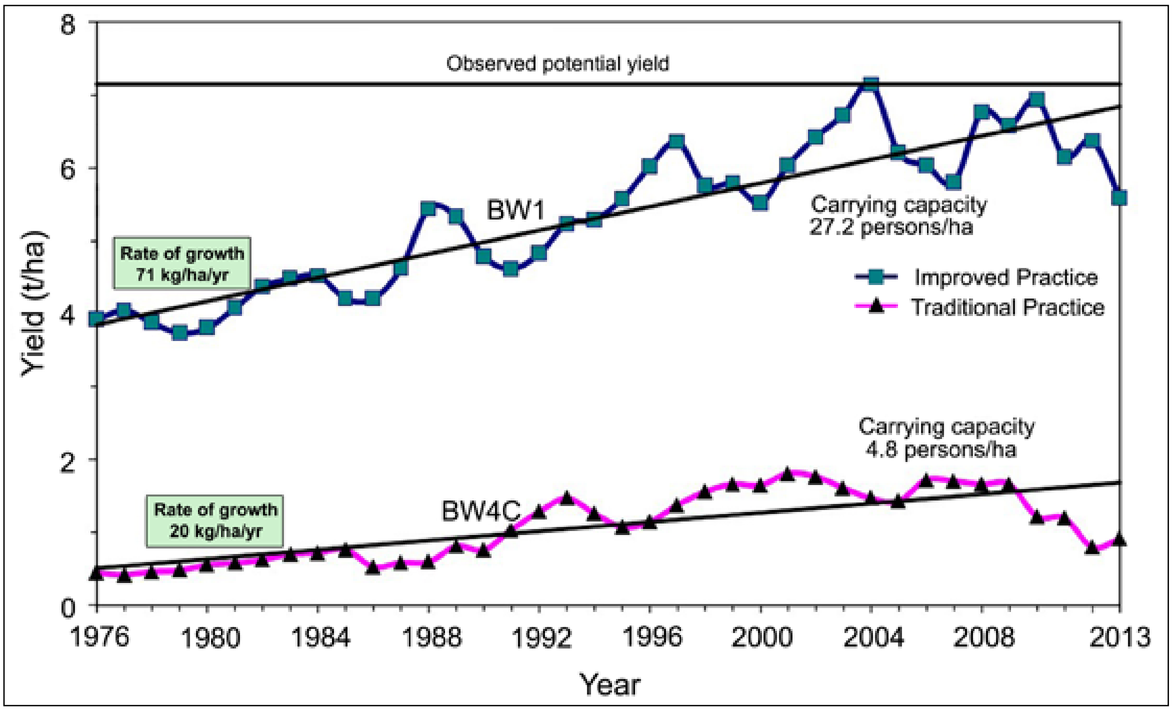


Figure 1. A comparison of harvested grain yield by implementing IWRM techniques in BW1 Vertisol heritage watershed at ICRISAT, Patancheru, India, and with traditional farmer's practices in BW4C.

One of the major concerns in rainfed areas was to rehabilitate existing vast tracts of degraded land and address water scarcity issues to ensure livelihood support. While realizing the importance of agriculture water management technologies, the GoI has initiated several programs to benefit rainfed areas (e.g., watershed development) since 1970s. Watershed programs initially adopted compartmental and top-down, supply-driven, contractual approach of soil and water conservation. Further, based on experience, participatory approaches were integrated along with the components for productivity enhancement and livelihoods in 2008-09. However, these programs were implemented in silos by different ministries and agencies without harnessing the synergies, learnings and most importantly without active participation of the community and technical backstopping of the programs**.**

Comprehensive assessment of watershed programs in India was undertaken by a ICRISAT-led consortium across the ministries, as requested by the GoI. This study across the country, revealed that 99 % of watershed projects were economically remunerative and were silently revolutionizing rainfed agriculture with a BCR of 2, while reducing runoff by 45 % and soil loss by 2-5 tons ha^{-1} yr^{-1}, increasing agricultural productivity by 50 to 400 % and cropping intensity by 35 %. Additional benefits like generating rural employment of 151 days ha^{-1} yr^{-1} (Wani et al. 2008; Joshi et al. 2008) were also noted. However, large scope existed for improving the performance of 68 % of the watershed projects, which were performing below average (Wani et al. 2008; Joshi et al. 2008). Programs adopted uniform technologies, presuming that one size fits all. This resulted in good performance in only 700 to 1,000 mm rainfall ecoregions, and the need for different strategies was indicated for low and high rainfall zones. Need for holistic and integrated livelihood approach through consortium and technical backstopping were identified as drivers of success from good case studies, out of 636 case studies that were analyzed (Wani et al. 2008; Joshi et al. 2008, Shiferaw et al. 2006, Sreedevi et al. 2006).

Watershed programs in the country underwent a great transformation in 2008, when all watershed programs were converged under one ministry and adopted a livelihoods approach (holistic system approach) and demand-based projects from the states, with increased emphasis on capacity building (GoI 2008 a, b). Although changes were made at the national level, many states still continued with the new watershed guideline programs in the 'business as usual' style, without internalizing the concept of convergence, collective and participatory livelihood approach, objective monitoring and evaluation using remote sensing and GIS tools. Urgent steps need to be taken in terms of institutional, technical, and policy innovations to harness maximum benefits using science-led and demand-driven watershed implementation. New watershed initiatives such as 'Neeranchal' would further upgrade the Integrated Watershed Development Program (IWMP).

In 2009, the Government of Karnataka (GoK) with technical support from the ICRISAT-led consortium, initiated a mission program 'Bhoochetana', and developed watersheds to help increase agricultural productivity in the state. In Bhoochetana, soil health mapping was used as an entry point activity and based on the soil health mapping of the whole state in 2009-10, balanced and integrated nutrient management recommendation for each *taluk* was developed and disseminated to farmers through farmer facilitators, wall writings, soil health cards and the internet. In addition, it ensured the availability of these inputs at the village level as well. Through the convergence of schemes, incentivized supply of micronutrients and improved seeds, and with an innovative monitoring and evaluation system, an increase in productivity for different crops by 20 to 66 % over the farmers' conventional management practices was recorded. During 2009 to 2013, more than 5 million farmers' benefitted and net economic benefits through increased production were estimated in the tune of US$353 million (₹ 1,963 crore). Based on the success of Bhoochetana project, the GoK decided to undertake an integrated systems approach, converging agriculture, horticulture and livestock in four districts, through a project named 'Bhoosamruddhi'. With technical support from eight international research institutions, along with state agricultural universities led by ICRISAT, this project is presently being implemented in all the districts in a phased manner. (GoK 2015).

In January 2015, the Government of Andhra Pradesh launched the Primary Sector Mission project 'Rythu Kosam' in all 13 districts of the state, by converging agriculture, horticulture, livestock, fisheries, marketing and rural development, with technical support from the ICRISAT-led consortium. In addition to convergence at the state level, another mechanism for convergence involved appointing a special Joint Collector at the district level, to allocate resources with accountability and implement the identified growth engines in different sectors. It is an innovative approach to break the existing silos and achieve convergence for attaining efficiency and impacts at the ground level.

Similarly, concerted efforts in Gujarat resulted in a large number of rainwater harvesting structures in farmers' fields. In addition, annual campaigns, soil health mapping and new technologies were helpful in increasing awareness in this region. Owing to this implementation, the state managed to achieve a 10 % annual growth rate as against the 2 to 3 % growth rate in the country, over the last decade.

All these examples showed that with a strong political will, remarkable impacts can be achieved in rainfed areas. Although good examples of improved technologies for increasing agricultural productivity and profitability in rainfed areas are available and demonstrated by scientists at pilot scales in different parts of the country, large-scale impacts have been eluding. Over the years, with increasing frequency of longer dry spells and droughts along with heavy intensity rainfall events, rainfed farmers are facing more difficulties and resorting to extreme steps like suicides. There is an urgent need to transform rainfed agriculture, not only for increasing agricultural production, profits and minimizing land degradation, but to make it attractive for youth and women as a respectable profession, by using scientific tools for mechanization, knowledge sharing, establishing market linkages and value addition. Such practices ensure larger share of benefits through processing, etc., that are retained in the villages with substantially increased investments, enabling policies and institutions. Projects such as Bhoochetana and Bhoosamruddhi in Karnataka; Rythu Kosam in Andhra Pradesh; gravity irrigation in Jharkhand and exceptional development in drip irrigation along with rural electrification and enhancing water resource availability through canal network in Gujarat, are a few examples of scaling up initiatives and harnessing benefits for the farmers. At the country level, such initiatives need to be scaled up through innovative technology-driven institutional mechanisms with decentralized accountability for achieving large-scale impacts.

4. Recommendations

4.1 Crosscutting issues for enhancing efficiency and success of the PMKSY

The success of PMKSY will depend on participatory planning, implementation and monitoring by adopting a result-based framework along with enabling integration and convergence to promote full-fledged implementation and monitoring. The following crosscutting strategies are essential for PMKSY's success.

4.1.1 Micro-watershed as implementation unit

The implementation unit should be a micro watershed (5,000 to 10,000 ha), which can be further integrated for planning purposes into meso- and macro-watersheds and subsequently to sub-basin and basin levels. Managing water efficiently under different agroecosystems is a challenging task. As discussed earlier, managing green and blue water resources in an integrated manner is the need of the hour and it can be done in the best possible way in a micro catchment i.e., watershed scale. These watersheds can be integrated into meso- and macro-watersheds and further into sub-basins and basins for effective planning, management, monitoring and achieving impacts. For efficient allocation of available water and its proper use, auditing and budgeting need to be undertaken at different watershed and basin scale. In India, good baseline work for characterizing macro- and micro-watersheds in basins is done by the National Remote Sensing Center (NRSC) and it has already been undertaken by all states for implementing IWMP. For effective implementation for all four components of the PMKSY program, the states can be charged to develop integrated water management plans starting from micro-watershed scale to district level for integration.

4.1.2 Convergence with MGNREGA and National Rural Livelihood Mission (NRLM)

The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) can benefit soil and water conservation efforts, as demonstrated in Andhra Pradesh, Madhya Pradesh and Telangana. Activities in the PMKSY need huge labor for undertaking soil and water conservation measures, as well as for enhancing the efficiency of water use and accelerating the benefits of irrigation and MGNREGA can be tapped for this. The convergence of MGNREGA with PMKSY program should be pursued vigorously in all states along with suitable allocation of resources (human/financial) for implementation of PMKSY. Investments made through MGNREGA can effectively harness the benefits through PMKSY from the planning stage itself. Detailed guidelines need to be developed, based on the experiences which can be of further help.

4.1.3 Better water management

Building awareness among farmers for efficient use of water is needed as they have the perception that excessive irrigation results in higher crop yields. However results show the opposite, causing land degradation, due to salinization and waterlogging.

Assured power supply and water quota allocation would transform the irrigation sector. However, the water allocation should be equitable, realistic and must be done in a transparent manner.

Integrated Water Resource Management (IWRM) framework needs to be developed and adopted urgently in addition to developing technologies to enhance green water use efficiency, conjunctive use of groundwater and surface water and proper drainage. This will help increase WUE, agricultural productivity, as well as family incomes and sustainable growth in command areas.

4.1.4 Integration of solar power into the PMKSY

Use of renewable energy like solar power needs to be integrated to enhance the impact of PMKSY and achieving sustainable development of agriculture. Solar power can be effectively used for pumping water from water harvesting structures (farm ponds) and to facilitate efficient irrigation systems like drip and sprinklers in the fields. The incentives provided for the use of solar power need to be integrated by adopting a single window approach, wherein, the department implementing PMKSY is provided financial resources from other departments responsible for incentivizing solar projects. One such example is the department of non-renewable energy. Such an approach would not only simplify the process of using solar power, but also result in larger impacts due to convergence and integration with efficient use of water in the agricultural fields. Good examples of solar power use can be seen in Gujarat and Rajasthan, and there is an urgent need to scale-up this initiative for achieving the goal of PMKSY.

4.1.4. Use of high-science tools for planning, implementation and monitoring

The success of a scheme like PMKSY cannot be achieved in a 'business as usual' style. Innovations in strategy, institutional mechanisms and policies are essential ingredients for its success. Planning for all the four components of PMKSY must be handled together. This can only be achieved by ensuring convergence of the existing actors while handling these components. Science tools like remote sensing images and data, water budgeting modeling tools, scenario development simulations along with GIS and soft skill planning participatory tools need to be used. Crop simulation models along with assessing market intelligence and effective capacity development are also essential. Systems modeling is another emerging technique which guides users on resource availability (groundwater, surface water, and soil moisture), its management and various alternatives, to achieve yield potential. Various studies demonstrated the use of hydrological tools to analyze upstream and downstream availability of water with the support of primary and secondary data (Garg et al. 2012). Others like ICT digital tools should also be integrated to achieve success.

4.1.5 Skill development

New skills such as simulation modeling, remote sensing, online monitoring, micro-irrigation, ICT-based knowledge dissemination, etc., need to be developed. This can be accomplished by retooling the present actors and bringing in new actors having expertise in the new science areas through contractual mode and subsequently forming new teams at the district, state and the national level. The success will not only depend on building capacity of the departments implementing this scheme, but also on the policy makers in the states, and the farmers who are accustomed to carrying out water management in a traditional, inefficient manner. Water management requires multiple interventions that jointly enhance the resource base and livelihoods of rural people. Capacity building programs should focus on water resources development, its conservation and efficient management. Thus, clear understanding of strategic planning, monitoring and evaluation mechanism and other expertise in the field of science and management is essential for all stakeholders. The stakeholders should be aware about the importance of various activities, their benefits in terms of economic, social and environmental factors. Therefore, organizing various trainings at different scales is important. The empowered actors would be accountable for effective planning, implementation and monitoring. Skill development for youth would not only generate employment opportunities in rural areas, but also benefit farmers by increasing farm productivity and profits**.** For example, a diploma in watershed management for empowering rural youth in Jharkhand, provides an opportunity for the Class 12 dropout youths, to get employment in the state watershed mission, NRLM, MGNREGA and different NGOs. Capacity building is a critical part for the successful implementation and capacities of existing institutions like WALMTARI, NIRD, state universities, research institutions and good NGOs can be strengthened. Services of international institutes like ICRISAT can be harnessed effectively.

4.1.6 Rejuvenating extension system

One of the reasons for large yield gaps between current yield and the potential yield that researchers achieve in a pilot site is the knowledge gap between 'What to Do' and 'How to Do it'? In spite of a number of new/improved technologies and products like improved crop cultivars available at research institutes and state agricultural universities, farmers continue to do their business in a traditional manner. The reasons are multifarious as the current knowledge delivery system, i.e., extension system, is inefficient and does not benefit the farmers. As per a recent national sample survey (70th Round), over 59 % of the farm households received no assistance from either government or private extension services. Of the 41 % households who have received extension assistance, only 11 % of the services came from physical government machinery –extension agents, Krishi Vigyan Kendras and agricultural universities. Farmers largely depended on other progressive farmers (20 %), media – including radio, television, newspaper (19.6 %) and private commercial agents (7.4 %) (National Sample Survey Office 2013). Therefore, there is an urgent need to reform the knowledge delivery systems in the states and the country by using innovative partnerships, tools, approaches and methods. Farmers in the states /country need to get high quality up-to-date and authentic information instead of getting conflicting information from different actors. It is not unusual that different scientists or staff from the same institution provide diametrically opposite advice to farmers. Past experiences suggest that the information delivery mechanism can be strengthened by utilizing the services of practicing farmers in the villages, through Farmers Field Schools and farmer facilitators, who stay in the villages most of their time, unlike outside experts who visit the villages once in a while (Wani et al. 2012). There should be efforts to bring in more pluralistic and partnership models in the field of extension.

Similarly, as there are no extension services on water, there is a need to build a cadre of water technicians offering end-to-end services, ranging from water conservation, to efficient water application, to water quality management. While public institutions are important to promote research and extension**,** the private sector also has an important role to play. Further, it is only through convergence and partnership building, that synergies can be harnessed to benefit farmers. The cadre of water technicians to support scientific management of water in the watershed can be developed through the concept of 'community resource person' or 'village resource person', which has been successfully experimented in various states under NRLM (GoI 2011). Similarly, a dedicated team of natural resource management experts, having knowledge of water, forestry, agriculture, livelihood and animal husbandry may also be created for effective knowledge dissemination.

4.1.7 Better agro advisory services

Day-to-day agricultural operations are weather sensitive. However, advances in weather sciences and the success rate of weather forecasts have now made it possible to predict weather more accurately than in earlier times. Weather forecasts for agricultural operations are required in terms of rainfall and its intensity, air temperature, wind speed and direction, and humidity to guide operations like spraying, irrigation and management of diseases. Incorporation of weather information into the management process is a difficult task because of the complex nature of interactions between weather and crops. Agromet Advisory Services (AAS) can be successfully rendered if the forecasts can be interpreted properly for taking on-farm decisions and educating farmers continuously. In India, the Integrated Agromet Advisory Service was started in 2007 by the Indian Meteorological Department (IMD) to help farmers on a real-time basis. Currently, agromet advisory content is limited to SMS-based services. In future, innovative tablet-based or email-based agromet advisories along with detailed information as wall writings in local language need to be promoted. A consortium of partners comprising of IMD, national and state research organizations, state agricultural universities, international research organizations, government departments, NGOs, and commercial companies, related to seed, fertilizer and plant protection, are needed for ensuring better advisory and identifying suitable adaptation strategies. Alternate cropping plan, critical inputs such as seeds, fertilizers, pesticides, manures and post-harvest strategies such as godowns, cold storage, and marketing information may also be made available through information centers at the state and district level with a 24x7 toll-free number to avail of the services.

4.1.8 Use of ICT in decision making, monitoring, impact analysis, knowledge dissemination

Lack of knowledge and information about input availability, improved technologies and welfare schemes, is one of the stumbling blocks for poor technology adoption. With increasing connectivity through the Digital India initiative of the GoI, there is wide scope for decision-making, monitoring, impact analysis and knowledge dissemination for resource optimization in agriculture and allied sectors using ICT. As trained human resource is a major constraint in the agriculture extension system, various ICTs are available which can bridge the gap between farmer and knowledge generator. For e.g., a dedicated web portal for farmers has been developed that caters to various services related to agriculture, including agroadvisory, weather and market information. On similar grounds, a few private organizations like Thomson Reuters and Indian Farmers Fertilizers Cooperative Limited (IFFCO)-Kisan Sanchar Limited (IKSL) have also initiated smart services for the farming community. Rapidly evolving information technology industry and favorable environment for ICT in agriculture, is giving a great boost to agricultural extension in India. Coordination among government and private companies is needed by developing or bringing them on to a common platform. Moreover, scientific tools such as GIS, remote sensing, and systems modeling can be integrated and used effectively to benefit farmers. Electronic DPR (using e-DPR software) preparation, using satellite imageries with ground truthing by technical experts, may be a good scientific tool for better decision making.

4.1.9 Convergence of different departments

Water management cannot be realized in isolation, as it involves different administrative wings of the government. Efficient irrigation requires an understanding of agriculture, sociology, hydrology, agriculture economics, marketing and agriculture engineering. Most irrigation departments are overwhelmingly staffed by civil engineers whose core competencies are in constructing large dams and canals. Therefore, there is a need to work collectively with other line departments (e.g., agriculture, horticulture, electricity boards, etc.) and other subject experts to optimize available water resources. Unfortunately, sectorial approach in management of agricultural systems has promoted silos with watertight boundaries. In reality, systems in agriculture work in an integrated and interactive manner to produce food and livelihood support systems. An effective means for convergence needs to be established as already substantial public investments are being made to strengthen rural economy and livelihood base of the poor. It calls for collective action and coordination among concerned stakeholders.

Convergence at the village level requires processes that bring about synergy in all the water and livelihood related activities. For instance, effective watershed management can be achieved when programs like Rashtriya Krishi Vikas Yojana (RKVY), MGNREGA, Swarnjayanti Gram Swarozgar Yojana (SGSY) and National Missions on Greening India, Energy, Sustainable Agriculture, Sustaining the Himalayan Ecosystem, etc., converge with private sectors initiatives to yield desired results. Convergence in the water sector, has evolved with the community watershed management model. By adopting a holistic watershed management approach, the community watershed is used as an entry point to converge and explicitly link watershed development with rural livelihoods and effective poverty eradication. In addition, it helps in facilitating the process of identifying policy interventions at different levels.

No single approach to irrigation (surface and groundwater) or watershed management, can work in the diverse socio-geographical regions of the country. The government and all other agencies will have to evolve the best technology and institutional arrangements for different regions of India. Focus should not be only on augmenting water resources, but also on improving irrigation efficiency, so that farmers can achieve more crops and income per drop of water used. We need to manage green, blue, as well as grey water efficiently in agriculture.

4.1.10 Partnerships and participatory management of resources

A watershed is a complex system with a multitude of problems. It requires a holistic approach that considers social, technical, economic, political and institutional factors to achieve specific social objectives (Dixon and Easter 1986; Wani et al. 2003). Past experience showed that enhancing partnerships and institutional innovations through a consortium approach was major impetus to harness the potentials of community watershed management, to reduce poverty and environmental degradation (Shambu Prasad et al. 2006). The underlying element of the consortium approach is to engage a range of actors to harness their strengths and synergies with the local community as the primary implementing unit. Through the consortium approach, complex issues can effectively be addressed by the joint efforts of key partners, namely the National Agricultural Research System (NARS), NGOs, government organization, international institutions like ICRISAT, agricultural universities, community-based organizations and other private interest groups, with farm households as the key decision makers. This strategy can build the capacity of members, such as women, towards management of conservation and livelihood development activities (Sreedevi et al. 2009). As demonstrated in the Andhra Pradesh Rural Livelihood Project (APRLP), the strongest merit of the consortium approach is in the area of capacity building where farm households are not the sole beneficiaries (Wani et al. 2003; Shambu Prasad 2006; Sreedevi et al. 2006). Similarly, easy access and timely advice to farmers are important drivers for the observed impressive impacts in the watershed, resulting in enhanced awareness of farmers and their ability to consult with the right people when problems arise. It requires multidisciplinary proficiency in the field of engineering, agronomy, forestry, horticulture, animal husbandry, entomology, social science, economics and marketing. It is not always possible to get all the required support and skills-set in one organization. Thus, consortium approach brings together the expertise of different areas to expand the effectiveness of various watershed initiatives and interventions.

4.1.11 Public-private partnership

Public-private partnerships (PPPs) are viewed as a governance strategy to minimize transaction costs and enhance coordination and enforce relations between partners engaged in production of goods and services. They enable an optimal policy approach to promote social and economic development, thus bringing together efficiency, flexibility and competence of the private sector along with the accountability, long-term perspective and social interest of the public sector. Over the years, GoI has developed policy responses to prioritize improvement measures for water resource generation (both for rainfed and irrigated areas) and better management practices (GoI 2008a,b,c,d). One of the processes of delivery promoted by the government since 2005, is PPPs, where watershed projects are jointly developed by the private sectors, NGOs and line departments (GoI 2006). Some lift irrigation schemes were also operated along with PPP, due to various management factors. In addition to water management, PPPs can play a greater role in linking farmers with markets along with value addition, achieved through establishment of processing units.

4.1.12 Crop land-use planning based on land and agroecological capability

India has varying agroecologies from arid, semi-arid to sub-humid and humid tropics with rainfall varying from 200 mm to 11,000 mm (Chirapunji, Meghalaya). In addition, soil types range from sandy soils in the desert to clayey to peat soils. The huge potential of these varying agroecologies can be harnessed through science-led planning and development, which would ensure sustainability as well as profitability to farmers, and ensuring food and nutritional security to the country. However, such land-use planning could be promoted through incentivizing farmers to adopt recommended cropping system. Another important issue is crop violation, a complex issue and intervention through convergence and better communication among different departments can resolve it. The intervention can help overcome the issue of conflicting policies such as creating irrigation infrastructure for providing supplemental irrigation to dryland irrigated crops on one hand and permitting a sugar factory in the region on the other.

Erring farmers have to be penalized by withdrawing incentives and market support for crops that are not to be grown in a given agroecological region. For e.g., in ecological systems like the arid and semi-arid regions, some farmers grow crops like rice and sugarcane using the precious groundwater, while other farmers struggle to provide a supplemental irrigation to the dying rainfed crop.

4.1.13 Seeing is believing - Sites of learning and innovations

The PMKSY is a science-led, participatory and innovative initiative. Its success not only depends on using proven technologies, but also on demonstrations before scaling-up. Hence, pilot sites can be established as exemplar sites in each district for training as well as development purposes. Such sites of learning should be developed by scientific institutions through a consortium approach and PPPs. These sites of learning can also provide field laboratories for undertaking strategic research in the area of land, water, crop and nutrient management strategies, as well as for impact assessment, and monitoring and evaluation studies in different agroecologies.

4.2 *Har Khet Ko Pani* through Integrated Watershed Management

A watershed is a natural entity, comprising of different land use types, from where rainwater drains into a common outlet (lake/river) and therefore watersheds can vary from a few hectares to a million hectares. People and livestock are integral parts of the watershed and their activities affect the productive status and health of watersheds and vice versa. A watershed is not simply a hydrological unit, but also a sociopolitical-ecological entity which plays a crucial role in determining food, social and economical security and provides a livelihood support system to the rural population (Wani et al. 2008). These watersheds provide various ecosystem services in the uplands and the inflow generated, supports the downstream ecosystem (such as irrigation availability in command areas). Currently, rainfed systems especially uplands face a number of challenges such as water scarcity, land degradation (due to over grazing and deforestation), poor productivity; and these areas are also the hotspots of poverty and malnutrition. Farmers who are solely dependent on agriculture, face high uncertainty and risk of failure due to various extreme events, water scarcity, pest and disease attack and market shocks. Therefore, integration of agriculture (on-farm) and non-agriculture (off-farm) activities is required at various scales for generating consistent source of income and support for their livelihoods. Among these challenges, water availability is the most important limiting factor, which needs to be addressed by adopting proper management practices at the farm and watershed scale. One of the objectives of PMKSY is to provide minimum water to every field (*Har Khet Ko Pani*) to sustain their crops, livestock and strengthen their livelihood support system. Integrated watershed management can be an effective means to achieve this goal and we have listed some recommendations for the holistic success of watershed management.

4.2.1 Ridge to valley approach

Although soil and water conservation practices are common interventions under watershed development programs, only a section of the community with large land holdings invest on groundwater extraction and benefit from it. This was because, issues related to non-treatment of watersheds from the ridge to valley, green water management and efficient utilization, were not addressed. Similarly, the traditional approach of constructing water harvesting structures was adopted by engineers and based purely on the experiences drawn from previous irrigation projects. They never realized that in rainfed agriculture, water management is entirely different and needs innovations, low-cost structures, distributed throughout the topo-sequence, to address issue of equity. Water harvesting structures, mainly masonry check dams are generally constructed at the downstream areas, thus ignoring upstream potential. A complete treatment of upstream areas by constructing low-cost water harvesting structures such as gabions, mini percolation tanks and gully control structures, etc., harvests 8-10 times more water than its storage capacity within the monsoon period. This not only helps to enhance the groundwater table right from the upstream areas but also controls flood and soil loss through siltation at the downstream. For e.g., Gark under-Garhkundar-Dabur watershed in Jhansi, Uttar Pradesh, enhanced the groundwater table by 2-3 m, by constructing low-cost water harvesting structures that not only enhanced base-flow, but also reduced soil loss by three times, compared to non-treated watersheds nearby (Singh et al. 2014). By constructing a series of low-cost structures across the first and second order streams, it helped provide more opportunities to infiltrate runoff water due to higher hydraulic gradient rather than allowing entire runoff to accumulate only at a few places of higher order stream at the downstream locations. It also addresses equity issues as more number of farmers are benefited through enhanced groundwater availability right from the upstream areas.

4.2.2 In-situ water conservation (Green water augmentation)

In integrated watershed management, the first and topmost priority should be *in-situ* moisture conservation by adopting appropriate landform formations (contour cultivation, bunding including gated bunds, broad bed and furrow, ridge and furrow, tied ridges, dead furrows, etc.), soil organic matter amendments, organic matter and stone/sand mulching and canopy management. Such measures are of great help, as water stored in soil is used productively for crop production rather than being lost through unproductive evaporation from tank storage. After saturating the soil profile, excess water should be harvested in a guided manner, in farm ponds or other storage structures in the farmers' fields, for use to supplement the crop water demand, during dry spells or to grow a second crop during the post-rainy season. Harvesting in ponds also ensures seepage and evaporation proof storage. Initial investments may be high, but considering the value of scarce water and the profits it can generate through protected cultivation, such investments are considered economically and environmentally sustainable.

4.2.3 Rainwater harvesting in farm ponds

Rainwater harvesting needs to be promoted at every farm in the rainfed areas as a drought proofing strategy. After saturating the soil profile, rainwater needs to be harvested in a technically planned farm pond of suitable size and type, thus ensuring seepage and evaporation proof storage. Here also, initial investment may be high but the profits it can generate through protected cultivation, makes it economically and environmentally sustainable.

4.2.3 Artificial groundwater recharge

Initially, farmponds are filled through harvested rainwater and later *ex-situ* and low-cost rainwater harvesting structures capture runoff throughout the topo-sequence for meeting common societal needs as well as ecosystem services such as groundwater recharging and ensuring environmental flows. During high intensity rainfall storms, sizable runoff amount is generated which could be stored in appropriate structures. Runoff and groundwater recharge is a highly sensitive water balance component as a slight change in rainfall pattern may lead to either flooding or significant reduction in blue water resources, especially in the arid and semi-arid tropical situation.

Evidences from different watersheds in India have confirmed that the water harvesting structures sustain good groundwater yield even after the rainy season. For instance, in Lalatora watershed of Madhya Pradesh, groundwater level in the treated area registered an average rise of 7.3 m; at Bundi watershed in Rajasthan, a 5.7 m increase was observed. In Adarsha watershed, Kothapally, Telangana, a study showed that nearly 30 to 60 % of the run-off water was harvested in different years through watershed management interventions. Water Harvesting Structures (WHS) resulted in an additional 3.5 m rise in water table during the monsoon as compared to the baseline. At the field scale, the zone of influence from such WHS was found between 200 and 400 m spatial scale (Garg and Wani 2012).

4.2.5 Groundwater management

With expansion of groundwater use along with change in land-use practices, most drylands in India are at semi-critical to critical stage of groundwater development. This shows that pumping is higher than resource replenishment. Practices such as promoting water intensive crops like banana/arecanut in low to medium rainfall regions such as Anantapur and Tumkur districts in southern India resulted in severe groundwater depletion in the last two decades. Most farmers who were cultivating crops like finger millet or groundnut converted their fields into orchards. There is no clarity on water budgeting and safe groundwater extraction and use in different rainfall zones and agroecological regions. In the absence of such information, farmers grow water intensive crops without considering the implications. All these culminated in most areas reaching critical development stage and resulted in higher energy consumption and loss of investment. To counter this, along with rainwater harvesting through ridge to valley approach, low water requiring crops need to be promoted. Moreover, a detailed study on water budgeting for different rainfalls and ecological regions is needed to map the existing water resources and its permissible safe use. Accordingly, the cropping patterns need to be promoted.

There is an urgent need to develop a policy framework to govern the use of groundwater resources. The first requirement for formulating effective policies is to shift from water resource development to water resource management. This is because, in many areas, development has already taken place, but its poor management might lead to the collapse of groundwater resource. Aquifer mapping and recharging needs to be undertaken on a priority basis. Also, groundwater quality deterioration with increased arsenic, nitrate, phosphates, heavy metals and pesticide content is a point of concern not only for meeting the drinking water needs, but also the use of poor quality groundwater for irrigation introduces arsenic, heavy metals and pesticides in the food chain. Such problem areas need urgent attention. Options to be considered include, a combination of legal measures with indirect regulation through power supply. Some important points for consideration are:

- Participatory management of groundwater through collective community action for natural resource conservation and management were demonstrated in integrated watershed management. The critical groundwater related decision of the community was to prohibit use of water directly from water harvesting structures for agricultural purposes. This had a major benefit of shifting farmers' minds and resources away from competition for stored water to providing cooperation on maximizing benefits from groundwater recharge, which they could access during off-seasons for cultivating cash crops such as vegetables. Therefore, there is a need to develop suitable policies for sustainable use of water to avoid overexploitation.
- Participatory groundwater management and sharing of borewells among farmers to ensure one rainfed crop through supplemental irrigation in a collective and cooperative mode, tried in some parts of the country could be scaled-up to manage groundwater in the region.
- Irrigation as per land-use capability will minimize the stress on water and land resources and enhance productivity alongside development of policies to avoid overexploitation of groundwater resources.
- There are no policies so far that address equity and management aspects of groundwater. Though certain regulations exist on groundwater exploitation, they are inadequate and ineffective. Even the proposed new policies are in line with these regulations rather than designing innovative policies that would integrate market and institutional dimensions of resource management. New policies should aim at integrating all sources of water in the regional context, rather than treating them in isolation. Demand management is equally important especially in the context of scarce resources, as the supplies are limited. Demand management helps in efficient and sustainable use of resources when compared to supply regulation.
- Presently, groundwater is regulated through synchronized supply of electricity rather than fixing electricity charges appropriately. Though this has helped in checking degradation in the short run, it is not an efficient solution in the long run. The future prospect of surplus power coupled with subsidized power prices would aggravate the process of environmental degradation and the resulting externalities. Therefore, economic pricing of electricity with proper monitoring facilities would be

more appropriate in order to internalize these externalities (Reddy 2005). In this context, Jyotigrama Yojana in Gujarat is an exemplar model for efficient supply of electricity, and can be scaled up in different states. However, states need to desist from launching popular schemes that have negative environmental impacts in the long run.

- Need-based application of water using water budgeting models, along with zone-wise crop planning and use of improved irrigation methods in rainfed systems, would help substantially in accelerating the benefits of groundwater irrigation.
- As MI increases WUE to a substantial extent, appropriate policy framework needs to be developed, making MI compulsory. This needs to be accomplished in a phased manner by educating and involving the community and private sectors including development agencies.

4.2.6 Zone-wise water harvesting guidelines for optimizing water resources

A comprehensive assessment on watershed development in the country showed that the current technologies worked well for medium rainfall ecoregions (700 to 1,100 mm), delivering better BCR and other parameters (Wani et al. 2008). For regions with rainfall less than 700 mm and higher than 1,100 mm, equivalent benefits could not be delivered because of water scarcity in some regions and excessive water availability in the other regions (Joshi et al. 2005). As one size does not fit all, different soil and water conservation practices should be defined for agroecological regions, thus emphasizing on budgetary allocations for different interventions as needed, rather than fixed allocations across the country. There is also a need to consider climatic variability such as frequency of occurrence of extreme events while designing the water harvesting protocols. Earlier studies demonstrated the benefits of low-cost water harvesting structures throughout the topo-sequence, which benefited a larger number of farmers than construction of masonry check dams (Wani et al. 2003; Garg and Wani 2012).

4.2.7 Agroecological zone-based cropping pattern

Groundwater irrigation has proved to be the largest source of irrigation in the last few decades. Since farmers themselves mainly fund the capital cost, its rate of growth and spread has been determined by the demand for water rather than availability of water resources or government funds. However, the substantial operational costs of pumping out water have been incentivized through power subsidies. Groundwater is being overexploited and many aquifers may not last unless there is focus on management and regulation of use through reforms. Watershed development, which enhances agricultural productivity in rainfed regions through soil and water conservation, has done much to alleviate the problems in non-irrigated regions and should be promoted. Cultivation of low water requiring crops in arid and semi-arid regions, should be encouraged by facilitating market linkages and appropriate pricing mechanism. Farmers cultivating high water requiring crops in such regions need to be discouraged by rationalizing power and other input subsidies.

4.2.8 Drought proofing and protected cultivation of high-value crops

In the absence of groundwater access, harvesting runoff by constructing farm ponds provides opportunity for supplemental irrigation for smallholder farmers in rainfed areas. Instead of providing irrigation to all the fields, a selected area with proper protection (polyhouse/shadenets) provided supplemental irrigation could be a better option to earn remunerative income by cultivating high-value crops. The remaining area can be utilized for growing less water requiring drought-tolerant crops along with fodder. As an example, Table 1 describes the amount of runoff generated from 1 ha land in different rainfall and soil classes, based on the hydrological monitoring at ICRISAT (Pathak et al. 2013). The required capacity of farm pond and water requirement for vegetable crops under protected cultivation is also estimated. Further, it shows the extent of area that could be cultivated potentially under protected farming in *kharif* (rainy season) and *rabi* (postrainy) season.

By harvesting surface runoff in water harvesting structures of desired capacity with proper lining and evaporation control measures, the harvested runoff amount is sufficient for cultivating 500 m^2 to 1,000

Table 1. Estimated runoff, water requirement, and net potential benefits by adopting protected cultivation in different rainfall and soil classes						
Soil Type	Vertisols			Alfisols		
Rainfall (mm)	600	800	1,000	600	800	1,000
Runoff coefficient from polyhouse	0.8	0.8	0.8	0.8	0.8	0.8
Runoff coefficient from fields	0.1	0.18	0.22	0.13	0.23	0.28
Potential Runoff Expected from field of 1 ha area (m^3)	552	1224	1760	702	1472	2240
Direct Runoff collected from Polyhouse considering 80% runoff coefficient	384	960	1,600	480	1,280	1,600
Total Amount of water harvested during monsoon (m^3)	936	2,184	3,360	1,182	2,752	3,840
Water requirement in *kharif* (mm)	480	480	480	480	480	480
Water requirement in *rabi* (mm)	360	360	360	360	360	360
Total water requirement (mm)	840	840	840	840	840	840
Potential polyhouse area based on harvest capacity (m^2)	1,114	2,600	4,000	1,407	3,276	4,571
Suggested polyhouse size (m^2)	800	1,500	2,000	1,000	2,000	2,000
Water required for one season; or minimum capacity of structure to be created (m^3)	384	720	960	480	960	960
Proposed capacity of water harvesting (m^3)	500	800	1,000	500	1,000	1,000
Cultivation in polyhouse (e.g., vegetable)						
Cost of polyhouse cultivation @ ₹ 160,000 ha^{-1} per season	12,800	24,000	32,000	16,000	32,000	32,000
Yield return @ 40 tons ha^{-1} and ₹ 15,000 ton^{-1}	48,000	90,000	120,000	60,000	120,000	120,000
Net income from two seasons per year from polyhouse	70,400	132,000	176,000	88,000	176,000	176,000
Agricultural Area (m^2) left for cultivating low water requiring dryland and fodder crops with residue moisture	9,200	8,500	8,000	9,000	8,000	8,000

m^2 polyhouse area, using improved methods of irrigation and mulching practices in both *kharif* and *rabi* season, depending on the soil classes. This may provide a net income of ₹ 70,400 to ₹ 176,000 yr^{-1} by cultivating high-value vegetable crops along with proper marketing facilities in different agroecological regions. The rest of the area can be cultivated with regular dryland crops along with fodder to support livestock population, which is one of the major livelihood support systems for dryland farmers.

4.2.9 Integrating livestock and income generating activities (IGAs)

For women and youth in rural areas, livestock, poultry and pig rearing can be integrated with other IGAs for improving livelihood as well as building resilience for adverse impacts of climate change on agriculture. Livelihood approach is the main pillar for integrated watershed management, to improve family incomes as well as food and nutritional security. Improved breeds of animals (cows, buffaloes, goats and poultry) along with proper feed regimes can immensely benefit farmers.

4.2.10 Decentralized wastewater reuse and integrating livestock for IGA

In rural areas, domestic wastewater is perennially available, causing health problems in water scarce regions. Domestic wastewater can be treated by adopting decentralized wetlands using mechanical filtration and phytoremediation to make it safe for agricultural use. In rainfed regions, livestock production relies mainly on common grazing areas, which are totally degraded and encroached, resulting in scarcity of fodder. Under India-EU collaborative project, ICRISAT-led consortium has developed a decentralized system and demonstrated that treated wastewater can be safely used for fodder production as well as flower cultivation in around 27 micro-watersheds. At the same time, it has also formed income-generating enterprises for women SHGs in the watershed areas. Decentralized wastewater treatment will also help in protecting the groundwater resources and downstream water bodies as currently, wastewater generated from the villages are directly disposed into nearby rivers or streams.

4.3. Recommedations for accelerated irrigation benefits program component of PMKSY

In irrigated agriculture, new interventions are necessary for enhancing efficiency, profitability, and sustainability. The following interventions could be strategized for enhancing the benefits of accelerated irrigation in the country.

4.3.1 Agroecological zone-based cropping pattern and crop diversification

- Past observations have shown that cropping patterns have shifted to water intensive crops (sugarcane, paddy, cotton, etc.) irrespective of rainfall and agroecological regions that lead to high water inputs and poor WUE in public-funded irrigation projects. These systems were designed considering that farmers would grow low water intensity crops with supplemental irrigation. Therefore, policy change in terms of promoting less water intensive crops with assured marketing and desired incentives are required. Crop diversification and zone-wise planning, use of improved irrigation methods with need-based release of water, using water budgeting models, would substantially help in accelerating the benefits of irrigation. To operationalize this proposition, a certain quantity of water must be allocated for cultivation of low water intensity crops, based on the available water balance. Additionally, if a farmer is willing to cultivate water intensive crops, they must pay for extra water utilization. It is important to have water pricing as well as proper monitoring mechanism on canal water use, at various sections (head, middle and tail ends) as there is a strong relationship between water price, water recovery, and performance of irrigation system. Similarly, to control excessive use of fertilizer, farmers should avail fertilizer subsidy benefits based on recommended dose of fertilizers, as per the soil-test-based results. Digital technologies could be efficiently harnessed to ensure proper implementation and monitoring. Application of extra dose of fertilizer than the recommended dose, should not be encouraged as extra application of fertilizer is neither profitable to the farmers nor the environment (soil, surface and groundwater).

  Increased availability of water in command areas has replaced time-tested scientific farming principles of crop rotations with widespread adoption of monocropping with cereals due to policies and market support. Command areas have lost their sustainability and resilience due to mono cropping with cereals, using heavy doses of subsidized chemical fertilizers and pesticides, continuous waterlogging and salinization of soils. Through innovative and enabling policies, crop diversification and rotation along with environment-friendly legume crops need to be promoted. Soil health assessment and soil test-based integrated fertilizer management as envisaged through another innovative scheme of soil health cards and direct benefit transfer of fertilizer subsidies to farmers' bank accounts using Aadhar (unique identity number) needs to be promoted and implemented in all command areas across the country.

4.3.2 Optimizing resource use through institutional and policy measures

For enhancing water use efficiency, awareness building among farmers is critical as this will help farmers to realize the current water scarcity scenario and judicious use. Integrated water resource management (IWRM) framework need to be strengthened to enhance available water resources.

Tube well irrigated areas

- Participatory management of groundwater through collective community action for natural resource conservation and management were demonstrated in integrated watershed management. The groundwater related decision of the community, to prohibit use of water directly from water harvesting structures for agricultural purposes had the major benefit of shifting farmers' minds and resources away from competition for stored water, towards providing cooperation on maximizing benefits from groundwater recharge, which they can access during off-seasons for cultivating cash crops such as vegetables. Therefore, there is a need to develop suitable policies for sustainable use of water to avoid overexploitation.
- Participatory groundwater management and sharing of borewells among farmers to ensure good yield of one rainfed crop through supplemental irrigation in a collective and cooperative mode, tried in parts of the country, could be scaled-up to manage groundwater.
- Irrigation as per land-use capability will minimize stress on water and land resources and enhance productivity alongside development of policies to avoid overexploitation of groundwater resources.
- Currently there are no policies that address equity and management aspects of groundwater and while certain regulations exist on groundwater exploitation, they are inadequate and ineffective. Even new policies proposed are in line with the regulations rather than designed innovatively to integrate market and institutional dimensions of resource management. New policies should aim at integrating all water sources in the regional context rather than treating them in isolation. Demand management is equally important especially in the context of scarce resources, as supplies are limited. Demand management helps in efficient and sustainable use of resources when compared to supply regulation.
- Groundwater is now being regulated through synchronized supply of electricity rather than fixing electricity charges appropriately. Though this has helped check degradation in the short run, it is not an efficient solution in the long run. The future prospect of surplus power coupled with subsidized power prices would aggravate the process of environmental degradation and the resulting externalities. Therefore, economic pricing of electricity with proper monitoring facilities would be more appropriate in order to internalize these externalities (Reddy 2005). In this context, Jyotigrama Yojana in Gujarat as an exemplar model for the efficient supply of electricity, can be scaled up in other states. However, states need to desist from launching popular schemes that have negative environmental impacts in the long run.
- Need-based irrigation using water budgeting models, with zone-wise crop planning and use of improved irrigation methods in rainfed systems, would help substantially in accelerating the benefits of groundwater irrigation.
- As MI increases WUE to a substantial extent, appropriate policy framework needs to be developed to make MI compulsory. This needs to be accomplished in a phased manner by educating and involving the community and private sectors as well as the development agencies.

Canal irrigated areas

- Improved infrastructure for efficient delivery of water to the farmers' fields through lined and solar panel covered canals or pipes would reduce transmission losses as well as unauthorized use of irrigation water. This is made possible by adopting the goal of 'zero flood irrigation by 2020' and popularizing MI systems with need-based irrigation scheduling for crops rather than calendar-based irrigation for fields using the water budgeting approach. Efficient usage needs to be promoted by making MI interventions mandatory. Farmers growing crops like sugarcane, paddy, vegetables etc., must be incentivized to adopt MI through PPP and participatory approaches.

- Flood irrigation is predominant in the canal command areas, which is one of the reasons for low WUE, waterlogging, salinity and poor acreage. Even in areas with warabandi (rotational method for equitable distribution of water) system in Punjab and Haryana, 70 % of the tail-end farmers got 54 to 70 % less water than what they were entitled to receive. Similarly, in the Tungabhadra canal command area in Karnataka, the tail-end farmers got 91 % less water than their actual entitlement, even though the project performance was claimed to be 90 % (Development Support Centre 2003). A major impact of this was, lower agricultural productivity of the tail-end farmers growing low-value crops or leaving land fallow (Oza 2007).
- Increasing areas of degraded lands in the command areas is largely due to the multifarious interacting factors such as excessive irrigation, poor drainage due to blockages of drains (siltation, construction of field roads, encroachments, cultivation, etc.), failure of the institutional mechanisms like Water Users' Cooperative Societies (WUCSs) and poor governance. This is a major concern and a complex issue that can be resolved only through capacity building, demonstrating that more water does not mean more crop productivity, which further helps build awareness among farmers.
- With improved method of irrigation (drip and sprinkler) and fertigation system along with need-based irrigation scheduling, 50 % of the additional area can be brought under irrigation even with limited water supply, compared to other conventional methods of irrigation. At the same time, this system would increase crop yield by 30-50 %, as water would be supplied as per the crop requirement, and will address waterlogging and salinity issues. This system should be encouraged in a phased manner with the involvement of the community, private sectors and development agencies. It is not possible to meet the challenge without substantial reforms in the irrigation institutions.
- Crop violation is a complex issue and intervention could be possible through convergence and better communication amongst different departments. The intervention can help overcome the issue of conflicting policies such as in terms of creating irrigation infrastructure for providing supplemental irrigation to dryland-irrigated crops and permitting establishment of a sugar factory in the region.
- Through crop diversification and zone-wise planning, use of improved irrigation methods with need-based release of water using water budgeting models would substantially help in accelerating the benefits of irrigation.
- Technical backstopping needs to be made available for farmers and responsibility for technical backstopping for each irrigation project could be entrusted to academic institutions in that particular project area. In addition, partnership backstopping can help strengthen the institutions.
- Enabling institutions paired with earnest implementation of policies along with increasing investments to improve the infrastructure.

4.3.3 Flood Water Management through Linking Water Storage Structures

With average annual rainfall of 1,100 mm along with spatial variability, a few regions face drought while other areas experience floods that adversely affect economic growth. The GoI along with state governments is investing huge amounts on disaster (drought and flood) management. In such situations, through remote sensing and geo-positioning of water bodies, floodwaters could be used effectively for filling water tanks in the nearby districts. Successful examples of implementing this system are available in Jalgaon district in Maharashtra where heavy rainfall in Nasik district caused floods and drought-affected Jalgaon district harvested the floodwaters. This arrangement not only ensured supplemental irrigation that saved crops but also recharged groundwater resulting in highest productivity, when compared to more than normal rainfall year in the district. Similarly, linking rivers in the state could provide a valuable solution for drought proofing vulnerable areas. The best example is the recently-completed Patti Seema project linking Godavari with Krishna to provide water to parched areas in Rayalaseema region of Andhra Pradesh.

4.3.4 Desiltation of water storage structures

The Inter-Ministry Task Force on large reservoirs maintains that one third of their storage capacity has been affected by siltation, resulting in reduced area under irrigation and lowering the life of the dam. In most cases, the rate of siltation is far in excess of the rate assumed during construction (Planning Commission 2002). Change in land use, deforestation and overgrazing are major reasons for heavy siltation in downstream water bodies. Proper implementation of watershed programs in the upper catchment areas of such structures, helps reduce flood situation and soil erosion by 50-300 % (Garg et al. 2012). Using remote sensing to estimate realistic possible water inflows, based on catchment areas, is necessary as the number of watershed development initiatives and encroachments in the upstream areas has altered water inflow estimates in several areas. In addition, expansion of need-based storage capacities of structures has to be undertaken through desiltation by considering realistic estimations of water inflows in the districts. Properly planned initiatives are needed to avoid unproductive investments where water inflows are not present. Through community participation, tank silt can be applied to farmers fields to enhance soil fertility.

4.4. Per Drop More Crop and Income

Current WUE in agriculture (rainfed and irrigated), 35 to 50 %, can be doubled to 65 to 90 % through large scaling-up interventions of scientifically proven improved management (land, water, crop and pest) options. The PMKSY scheme enables us to handle green and blue water resources together by adopting holistic and integrated water management approach. As indicated earlier, all four components of the PMKSY need to be implemented concurrently and together in rainfed or irrigated areas with micro-watersheds as the implementing unit in the districts. Measures to enhance WUE are discussed at various places in this strategy paper and are reiterated here only for the purpose of continuity.

- Efficient use of rainwater stored in soil as soil moisture (green water)
- Conjunctive use of blue water through rainwater harvesting in farm ponds
- Improved landform for efficient irrigation and water management
- Protected cultivation of high-value crops
- Soil test-based integrated nutrient management
- Improved crop management practices
- Efficient irrigation using micro irrigation (zero flood irrigation)
- Water balance based irrigation scheduling in place of calendar-based irrigation scheduling
- Crop rotations and intercrops
- Improved crop cultivars (drought tolerant and water efficient)
- Integrated pest and disease management
- Enabling policies and innovative institutional mechanisms
- Organic matter amendments through *in-situ* generation of green manuring and composting (vermicomposting and aerobic composting)
- Minimum tillage

4.4.1 Improved method of irrigation system

Despite water scarcity, water is carried through open channels in most of the farmers' fields, and are usually unlined, resulting in large amount of water lost through seepage. In India, farmers irrigate lands rather than crops. For e.g., in Alfisols and other sandy soils (with > 75 % sand), lining of open field channel, covering channels with solar panels, as in Gujarat, or use of irrigation pipes, is necessary to reduce high seepage and evaporation losses, leading to enhanced productivity and profitability. Use of closed conduits (plastic, rubber, metallic and cement pipes) need to be promoted (Pathak et al. 2009) for achieving high WUE. In general, MI systems are applied for high-value and horticulture crops, but MI in field crops also needs to be promoted, to address issues of groundwater depletion and water scarcity. Awareness about new MI methods such as sub-surface drip, need to be created through demonstrations. Drip irrigation for crops like wheat, paddy, oilseeds, cereals and pulses need to be actively promoted. Also, for water logging crops like sugarcane and banana, MI should be made mandatory.

4.4.2 Water balance model-based irrigation scheduling

For efficient use of available water, need-based irrigation scheduling can further enhance use efficiency and at the same time produce better yields. Farmers, in general, adopt calendar-based irrigation scheduling irrespective of the variability in soil physical parameters (water holding capacity, soil depth, etc.) resulting in either excess or deficit water application. ICRISAT has developed a simple decision-making tool 'water impact calculator' for irrigation scheduling, which requires elementary field data and its management information. It provides entire irrigation scheduling for a season as per water balance approach. Water impact calculator used at various locations showed that a minimum of 30 % water could be saved by following need-based irrigation scheduling without compromising on crop yield. Similar decision-making tools need to be promoted for optimizing water resources.

4.4.3 Normalization of micro-irrigation policy incentive guidelines

Despite huge promotion of micro-irrigation, there is a large time lag between the decision taken about the subsidy and actual implementation. Currently, different government departments or agencies are involved in the implementation of subsidy-oriented schemes. Due to variation in the norms, it is difficult to get all the details as and when required about the scheme (Palanisami et al. 2011). Moreover, differential subsidy pattern for different crops is being followed in different regions and is affecting farmers and implementing agencies, to follow and avail the benefit in a given scheme. Hence, it is important to introduce a uniform subsidy across the state.

4.4.4 Rainy season fallow management

Vertisols and associated soils which occupy large areas globally (approximately 257 million ha, (Dudal 1965)) are traditionally cultivated during the postrainy season on stored soil moisture. Due to poor infiltration rates and waterlogging, farmers' face difficulties to cultivating such lands during the rainy season. It is perceived that the practice of fallowing Vertisols and associated soils in Madhya Pradesh, India have decreased after the introduction of soybean. However, 2.02 million ha of cultivable land is still kept fallow in Central India, during *kharif* (rainy) season (Wani et al. 2002; Dwivedi et al. 2003). On-farm soybean trials conducted by ICRISAT involving improved land configuration (Broad Bed Furrow system) and short-duration soybean varieties, along with growing chickpea with minimum tillage in *rabi* (postrainy) season, enhanced the cropping intensity. In Guna, Vidisha and Indore districts of Madhya Pradesh. Increased crop yields (40-200 %) and incomes (upto 100 %) were realized with landform treatment, new varieties and other best-bet management options (Wani et al. 2008) through crop intensification.

4.4.5 Rice fallow management for crop intensification

Considerable amount of green water is available after the monsoon, especially in rice fallow systems, which could be easily utilized by introducing a short duration legume crop with simple seed priming and micronutrient amendments (Kumar Rao et al. 2008; Wani et al.2009; Singh et al. 2010). Of the 14.29 million ha (30 % of rice growing area) rice fallows available in the Indo Gangetic Plains (IGP), spread across Bangladesh, Nepal, Pakistan and India, about 11.4 million ha (82 %) are in the Indian states of Bihar, Madhya Pradesh, Chhattisgarh, Jharkhand, West Bengal, Odisha and Assam (Subba Rao et al. 2001).Taking advantage of the sufficiently available soil moisture, after harvesting rice crop, during the winter season in eastern India, growing early maturing chickpea in these rice fallows, with best-bet management practices, provides opportunity for intensification (Kumar Rao et al. 2008; Harris et al. 1999). An economic analysis has shown that growing legumes in rice fallows is profitable for farmers with a BCR exceeding 3 for many legumes. In addition, utilizing rice fallows for growing legumes could result in generating 584 million person-days employment for South Asia in additon to making India self-sufficient in pulses production.

5. Institutional Arrangements for Operationalizing PMKSY

- The PMKSY mission calls for partnerships with many actors, including PPPs approach, with scientific institutions providing technical backstopping.
- There should be a three-tier system for implementation of PMKSY through a single window system at national, state and district levels, as the implementation will be at the watershed/catchment scale at district level, and finally integrating at the basin level. The implementation of the PMKSY is proposed to be undertaken in a mission mode with a Director General (DG) at the national level who could ensure convergence across departments. All financial and human resources of the PMKSY should be allocated to the mission DG with clear accountability, by putting a 'single window' system in place.
- The mission DG's office needs to have divisions for planning and budgeting, implementation, monitoring and evaluation, and capacity building, each led by efficient people with proven record of enabling and facilitation skills to build partnerships, as well as get participatory approaches implemented, suitably in their respective divisions.
- The implementing agency should have a multi-disciplinary team to understand agriculture, sociology, hydrology, agriculture economics, capacity building and agriculture engineering as implementation of irrigation and watershed management activities needs specialized skills.
- The mission DG needs to be supported by the PMKSY Advisory Board, comprising of well-known technical experts from national and international institutions; secretaries of participating and associated departments such as agriculture, watershed development, water resources, horticulture; financial institutions like NABARD, NRSC, NGOs, etc.
- Similar structure would be needed at the state [State Level Nodal Agency (SLNA)] as well as district levels [District Level Nodal Agency (DLNA)] along with the divisions and advisory boards. At state level, the nodal agency could be led by the Chief Secretary and at district level, the nodal agency could be led by the District Collector/Magistrate.
- As the PMKSY would be adopting science-led development approach, well-known renowned experts at all levels must be roped in, not only for the Advisory Boards, but also for innovations, demonstrations and establishing sites of learning across the country.
- At the district level, a dedicated institution needs to be created or converged with the district watershed development unit and the major responsibility of this unit should be to oversee the implementation of irrigation and watershed programs in each district. This unit will have separate independent accounts for each component of the PMKSY.
- Best possible convergence could be possible at district level under the leadership of the District Collector/Magistrate. The funding should flow directly to the district level dedicated unit as per the GoI norms. A single account at the state level may be made for the SLNA in the pattern of NREGA Soft. This software developed by National Informatics Centre (NIC) may be customized for the state situation. The officers at different levels like Gram Panchayat, Block and District, are authorized for generating Fund Transfer Orders (FTO). Goods and services procured for PMKSY may be directly transferred to beneficiaries through FTOs, without delay. At the district level, DLNA will identify potential implementing agencies in consultation with the SLNAs as per the guidelines decided by the respective state governments. The DLNA would facilitate coordination of relevant programs of agriculture, Command Area Development Authority, minor irrigation, horticulture, rural development, animal husbandry, etc., with the watershed and irrigation projects. At Taluk/Block/Mandal level, Panchayati Raj institutions must play a greater role.
- The PMKSY needs to be resourced fully as indicated in the potential benefit section (6). Estimated cost of incentives for the PMKSY works out to be ₹ 251,665 crore, in additon to additional management, implementation and monitoring costs.

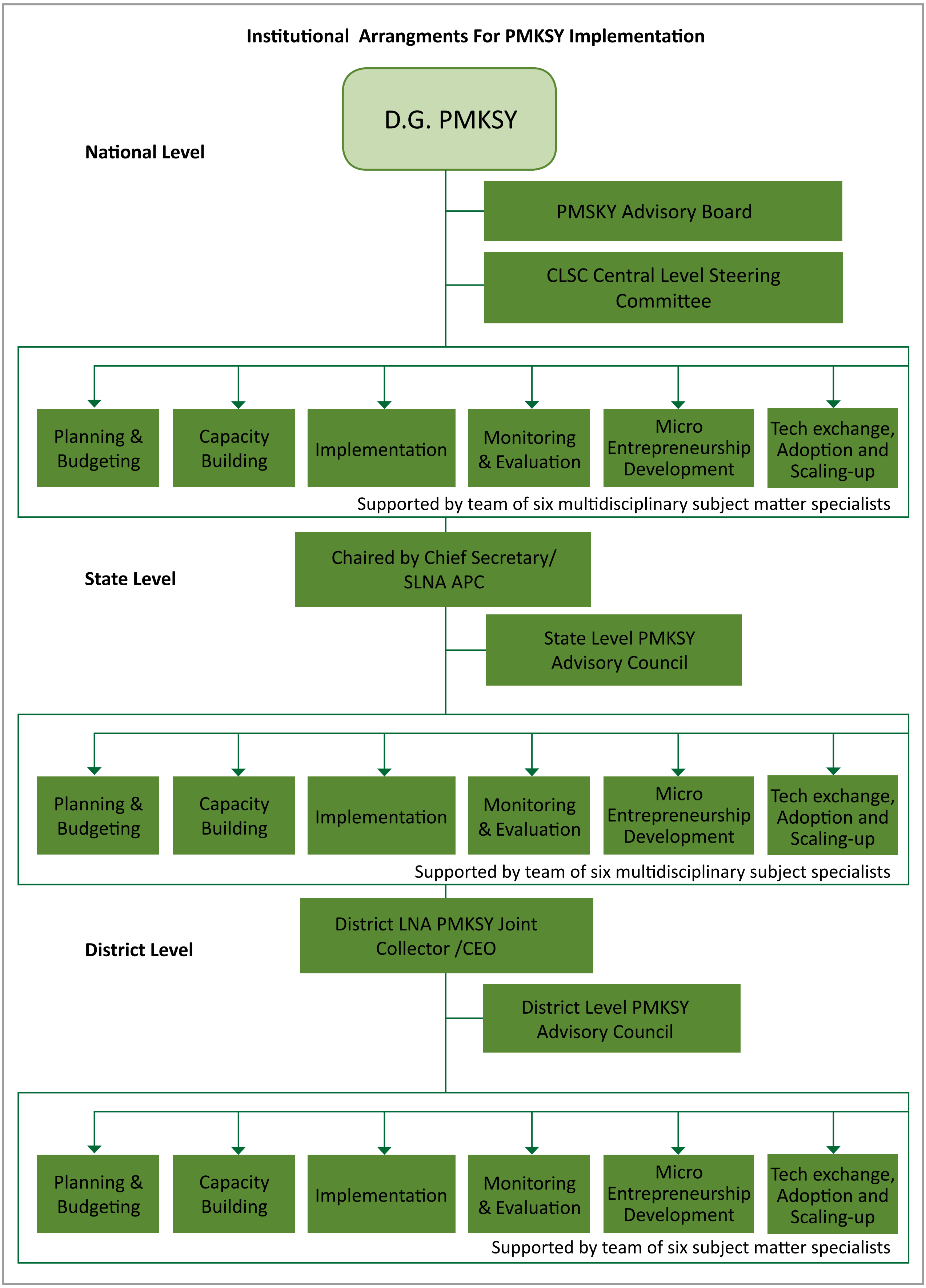


Figure 2. Institutional arrangement for PMKSY implementation.

6. Potential Benefits of Proposed Innovations

The most important and direct benefit of the PMKSY will be increased efficiency of scarce water resources in the country for increasing agricultural production, profitability and most importantly long-term sustainability of agriculture. The economic returns, as estimated by undertaking ex-ante impact assessment, showed that in 10 years, the PMKSY would add total value of ₹ 23 lakh crores to GDP, with a total investment of ₹ 466,850 crores and the BCR at macro level would be 9.2:1. The share of state and central governments in the investment, which would be in the form of incentives, is estimated at ₹ 251,665 crores, while farmers' contributions would form the rest (10 % in watersheds and 50 % in other interventions). Additional 10% resources for implementation, capacity building and establishing sites of learning, will be needed for successful implementation of the PMKSY. For individual farmers, the benefit would vary from 3,000 to 150,000 ha^{-1} yr^{-1} with different technologies.

In addition to direct economic benefits to farmers and the government, the additional production would ensure food security as well as profitability to farmers. Most importantly, through enhanced water and land-use efficiency, sustainable development could be achieved, while creating millions of jobs such as water technicians, farmer facilitators, protected vegetable cultivation technicians and value chain experts. This will also strengthen agriculture related industry development, while marketing and processing will generate growth and tax revenue to the government.

7. Conclusion

The PMKSY program will help India address the issue of increasing food production, with the limited land and water resources available, by adopting integrated water resource management framework. It would help in drought proofing rainfed agriculture and at the same time enhance sustainability of irrigated agriculture by minimizing land degradation due to salinization, waterlogging, and imbalanced use of chemical fertilizers. It also addresses issues of equity of water access on one hand, while dealing with food and nutritional security for the growing population on the other. As envisaged in the paper,

Table 2. Summary of ex-ante impact analysis.

Interventions	Area (Million ha)	Cost of intervention (₹ ha^{-1})	Total investment (crore)	Net benefit (crore)	BCR including full cost	Total investment by the GoI (crore)	BCR including farmers' contribution
Rainfed system							
Protected cultivation	19	150,000	285,000	1,609,300		142,500	
Watershed management	38	12,000	45,600	144,513		41,040	
Sub Total (Rainfed system)			330,600	1,753,813	5.30	183,540	9.6
Irrigated system							
Surface water	10.5	25,000	26,250	340,200		13,125	
Groundwater	22	50,000	110,000	217,800		55,000	
Sub Total (Irrigated system)			136,250	558,000	4.10	68,125	8.2
Total project (Full cost)			466,850	2,311,813	4.95	251,665	9.2

Note: We have considered 10% farmers' contribution in watershed management and 50% for groundwater irrigated and surface water irrigated interventions. Additional 10% resources for implementation, trainings and establishing the sites of learning will be needed.

adopting mission approach and ensuring convergence at different levels from macro-watersheds at district level to basin, state and national level, would enhance WUE and ensure sustainable development of water resources in the country. By building partnerships through PMKSY with different partners including farmers, extent agents, implementing agencies, private companies and government functionaries of different line departments, smallholder farmers would derive tangible economic benefits with increased production and value through the value-chain approach in the mission mode.

In addition to the above benefits, most importantly, the additional economic returns of ₹ 23 lakh crore will be added to the GDP in 10 years, triggering agriculture related industrial growth and revenue generation in addition to employment generation for several millions of youths in the country.

References

Amarasinghe, Upali A and **Sharma Bharat R.** 2008. Benefits of Irrigation Water Transfer in the National River Linking Project: A Case Study of the Godavari (Polavaram)-Krishna Link in Andhra Pradesh. Strategic Analysis of the National River Linking Project (NRLP) on India 2: 173–193.

Anantha KH. 2013. Economic implications of groundwater exploitation in hard rock areas of southern peninsular India. Environment, Development and Sustainability, 15:587–606.

Anantha KH and **Raju KV**. 2008. Groundwater over-exploitation, cost and adoption measures in the central dry zone of Karnataka. Working Paper 202. Institute for Social and Economic Change. 32 pp.

Apoorva Oza. 2007. India Infrastructure Report 2007. part i irrigation: achievements and challenges. Pages 178-196. (http://www.iitk.ac.in/3inetwork/html/reports/IIR2007/07-Irrigation.pdf)

Asolekar SR, Kalbar PP, Chaturvedi MKM, Maillacheruvu KY. 2015. Rejuvenation of rivers and Lakes in India: Balancing Societal Priorities with Technological Possibilities. Earth Systems and Environmental Sciences, from Comprehensive Water Quality and Purification, 4, 181-229,

Boomiraj K, Wani SP, Garg KK, Aggarwal PK and Palanisami K. 2010. 'Climate change adaptation strategies for agro-ecosystem-a review'. Agrometeorology 12 (2), 145-160

Buechler S and **Scott C**. 2006. Wastewater as a Controversial, Contaminated yet Coveted Resource in South Asia. Human Development Report Office Occasional paper, Human Development Report 2006. UNDP. pp 9.

Buechler S and **Devi G.** 2005. Local Responses to Water Resource Degradation in India: Groundwater Farmer Innovations and the Reversal of Knowledge Flows. The Journal of Environment and Development 14(4): 410-438.

Dewandel B, Perrin J, Ahmed S, Aulong, Hrkal Z, Lachassagne P, Samad M and Massuel S. 2010. Development of a tool for managing groundwater resources in semi-arid hard rock regions: application to a rural watershed in South India. Hydrological Processes24: 2784–2797.

Dixon John A and William Easter K. 1986. Integrated Watershed Management: An Approach to Resource Management. Pages 3-16 *in* Watershed Resources Management: an Integrated Framework with Studies from Asia and the Pacific (Easton M, William K, Dixon JA and Hufschmidt MM, eds.). Westview Press: East-West Center, Honolulu, HA.

DSC. 2003. Proceedings of the 'National Workshop on Tail-enders and other Deprived, Development Support Centre, Ahmedabad.

Dudal R. 1965. Dark clay soils of tropical and subtropical regions. FAO Agric. Dev. Paper 83, 161 pp.

Dwivedi RS, Ramana KV, Wani SP and **Pathak P**. 2003. Use of Satellite Data for Watershed Management and Impact Assessment. Pages 149-157 *in* Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia. (Wani SP, Maglinao AR, Ramakrishna A and Rego TJ, eds.). Proceedings of the ADB-ICRISAT-IWMI Project Review and Planning Meeting, Hanoi, Vietnam, 10-14 Dec 2001. Patancheru, 502 325, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Falkenmark M, Rockström J and **Karlberg L. 2009. 'Present and future water requirements for feeding humanity'.** *Food Security 1: 59–69.*

Garg KK, Karlberg L, Barron J, Wani SP and **Rockström J.** 2012. 'Assessing impact of agricultural water interventions at the Kothapally watershed, Southern India'. *Hydrol. Processes* 26 (3), 387–404.

Garg KK and **Wani SP.** 2012. 'Opportunities to build groundwater resilience in the semi-arid tropics'. Groundwater National Ground Water Association, *Groundwater* 51 (5), 679-691.

Godfray HC, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM and **Toulmin C.** 2010. 'Food Security: The Challenge of Feeding 9 Billion People'. *Science* 327 (5967), 812-818

Government of India. 2006. Towards Faster and More Inclusive Growth: An Approach to the 11th Five Year Plan. Planning Commission, New Delhi.

Government of India. 2008a. Common Guidelines for Watershed Development Projects, Department of Land Resources, Ministry of Rural Development and Panchayat Raj, New Delhi.

Government of India. 2008b. Planning Commission. Eleventh Five Year Plan 2007-2012, vol. II. Oxford University Press, New Delhi.

Government of India. 2008c. Planning Commission. Eleventh Five Year Plan 2007-2012, vol. III. Oxford University Press, New Delhi.

Government of India. 2008d. Planning Commission. Eleventh Five Year Plan 2007-2012, vol. 1. Oxford University Press, New Delhi.

Government of India. 2011. National Rural Livelihood Mission (NRLM). Ministry of Rural Development, Government of India, New Delhi.

Government of India. 2013. Master Plan for Artificial Recharge to Ground Water in India. Ministry of Water Resources and Central Ground Water Board, New Delhi.

Government of India. 2014. Agricultural Statistics at a glance 2014. Government of India, Ministry of Agriculture, Department of Agriculture & Cooperation, Directorate of Economics & Statistics

Government of Karnataka. 2015. Agriculture Budget Speech.

Harris D, Joshi A, Khan PA, Gothkar P and **Sodhi PS**. 1999. On-farm seed priming in semi-arid agriculture: development and evaluation in maize, rice and chickpea in India using participatory methods. *Experimental Agriculture* 35:15–29.

Joshi PK, Jha AK, Wani SP, Laxmi Joshi and **Shiyani RL.** 2005. Meta-analysis to assess impact of watershed program and people's participation. Comprehensive assessment Research Report 8, Colombo, Sri Lanka: Comprehensive Assessment Secretariat. *In* Watershed Management Challenges: Improved Productivity, Resources and Livelihoods (Bharat R Sharma, Samra JS, Scott CA and Wani SP eds). Sri Lanka, IWMI. 18 pp.

Joshi PK, Jha AK, Wani SP, Sreedevi TK and **Shaheen FA**. 2008. Impact of Watershed Program and Conditions for Success: A Meta-Analysis Approach. Global Theme on Agroecosystems, Report 46. International Crops Research Institute for the Semi-Arid Tropics and National Centre for Agricultural Economics and Policy Research

Kumar Rao JVDK, Harris D, Kankal M and **Gupta B. 2008. Extending** *rabi* cropping in rice fallows of eastern India. Pages 193-200 *in* Improving agricultural productivity in rice-based systems of the High Barind Tract of Bangladesh, (Riches CR, Harris D, Johnson DE and Hardy B, eds.). Los Banos, Philippines: International Rice Research Institute

Molden D, ed. 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan. 645 pp.

NSSO (National Sample Survey Organisation). 2013. Situation assessment survey of Agricultural households in India (70th round: July 2012-June 2013). New Delhi: Ministry of Statistics and Programme Implementation.

Palanisami K, Kadiri Mohan, Kakumanu KR and **Raman S.** 2011. Spread and Economics of Micro-irrigation in India: Evidence from Nine States, Economic & Political Weekly. XLVI (26 & 27): 81-86.

Pathak P, Sahrawat KL, Wani SP, Sachan RC and **Sudi R.** 2009. Opportunities for water harvesting and supplemental irrigation for improving rainfed agriculture in semi-arid areas. Pages 197-221 *in* Rainfed agriculture: unlocking the potential (Wani SP, Rockström J and Oweis T, eds.). Comprehensive Assessment of Water Management in Agriculture Series. Wallingford, UK: CAB International.

Pathak P, Sudi R, Wani SP and **Sahrawat KL** 2013. Hydrological behavior of Alfisols and Vertisols in the semi-arid zone: Implications for soil and water management, Agricultural Water Management Vol. 118, 12– 21.

Planning Commission. 2002. Tenth Five Year Plan, Planning Commission, New Delhi.

Rao AVRK, Wani SP, Singh K, Ahmed MI, Srinivas K, Bairagi SD and **Ramadevi O.** 2013. Increased arid and semi-arid areas in India with associated shifts during 1971-2004. Journal of Agrometeorology, 15 (1): 11-18.

Reddy VR. 2005. Costs of resource depletion externalities: A study of groundwater overexploitation in Andhra Pradesh, India. Environment and Development Economics 10: 533-556.

Rodell M, Velicogna I *and* **Famiglietti J***. 2010.* Satellite-based estimates of groundwater depletion in India. Available at: http://www.nature.com/nature/journal/v460/n7258/abs/nature08238.html

Rockström J, Hatibu N and **Oweis T**. 2007. Managing Water in Rainfed Agriculture. In. Molden D. (editor) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Chapter 9: 315-348. Earthscan, London.

Rockström J and **Karlberg L.** 2009. 'Zooming in on the Global Hotspots of Rainfed Agriculture in Water constrained Environments'. In *Rainfed Agriculture: Unlocking the Potential*.

Scanlon BR, Jolly I, Sophocleous M and **Zhang L.** 2007. 'Global impacts of conversions from natural to agricultural ecosystems on water resources: Quantity versus quality'. *Water Resource Research* 43: W03437. doi:10.1029/2006WR005486.

Shambu Prasad, Laxmi CT and **Wani SP** 2006. Institutional Learning and Change (ILAC) at ICRISAT: A Case Study of the Tata-ICRISAT Project. Global Theme on Agroecosystems Report no. 19. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 44 pp.

Shah Amita. 2007. 'Benchmark Survey for Impact Assessment of Participatory Watershed Development Projects in India'. Report submitted to Planning Commission, Government of India, New Delhi, India, pp 14.

Shah Amita, Wani SP and **Sreedevi TK** (eds.) 2009. Impact of Watershed Management on Women and Vulnerable Groups. Proceedings of the Workshop on Comprehensive Assessment of Watershed Programs in India, 25 July 2007. ICRISAT, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 184 pp.

Shah T. 2011. Past, Present, and the Future of Canal Irrigation in India. India Infrastructure Report 2011, 70-87.

Shiferaw B, Anupama GV, Nageswara Rao GD and **Wani SP**. 2006. Socioeconomic Characterization and analysis of resource-use patterns in Community Watersheds in Semi-Arid India. Journal of SAT Agricultural Research, An e-Journal published by ICRISAT, Vol (2): Issue.

Singh P, Pathak P, Wani SP and **Sahrawat KL.** 2010. Integrated watershed management for increasing productivity and water use efficiency in semi-arid tropical India. in Water and Agricultural Sustainability Strategies (Manjit S Kang, Ed.). CRC Press, The Netherlands. pp 181-205

Singh R, Garg KK, Wani SP, Tewari RK and **Dhyani SK.** 2014. Impact of water management interventions on hydrology and ecosystem services in Garhkundar-Dabar watershed of Bundelkhand region, Central India'. *Journal of Hydrology* 509, 132-149.

Sood A and **Mathukumalli BKP.** 2011. Managing international river basins: reviewing India–Bangladesh transboundary water issues. International Journal of River Basin Management 9 (1): 43-52.

Sreedevi TK, Wani SP and **Sudi R.** 2006. On-site and Off-site Impact of Watershed Development: A Case Study of Rajasamadhiyala, Gujarat, India. Global Theme on Agroecosystems Report No. 20. Patancheru 502 324, Andhra Pradesh, India: ICRSIAT. 48 pp.

Sreedevi TK, Wani SP and **Nageswara Rao V.** 2009. Empowerment of Women for Equitable Participation in Watershed Management for Improved Livelihoods and Sustainable Development: An Analytical Study. Shah A, Wani SP and Sreedevi TK (eds.). Impact of Watershed Management on Women and Vulnerable Groups. Proceedings of the Workshop on Comprehensive Assessment of Watershed Programs in India, 25 July 2007, ICRISAT, Patancheru 502 324, Andhra Pradesh, India. ISBN: 978-92-9066-523-6: CPE 166. 184 pp.

Subbarao GV, Kumar Rao, JVDK, Kumar J. 2001. Spatial distribution and quantification of rice-fallows in South Asia – potential for legumes. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Verma, Anju, Biswajeet Thakur, Shashwat Katiyar, Dharam Singh and **Madhu Rai.** 2013. Evaluation of ground water quality in Lucknow, Uttar Pradesh using remote sensing and geographic information systems (GIS). International Journal of Water Resources and Environmental Engineering, 5(2): 67-76.

Vijay Shankar PS, Kulkarni H and **Krishnan S.** 2011. "India's groundwater challenge and the way forward". Economic and Political Weekly, 56 (2), 37-45.

Vinod PN, Chandramouli PN and **Koch M**. 2015. Estimation of Nitrate Leaching in groundwater in an Agriculturally Used Area in the State Karnataka, India, Using Existing Model and GIS. Aquatic Procedia, 4, 1047-1053

Wani SP, Pathak P, Tam HM, Ramakrishna A, Singh P and **Sreedevi TK.** 2002. Integrated watershed management for minimizing land degradation and sustaining productivity in Asia. In: Integrated Land Management in the Dry Areas. (Zafar Adeel Ed.), pp 207-230. Proceedings of a Joint UNU-CAS International Workshop, 8-13 September 2001, Beijing, China, United Nations University, Tokyo, Japan.

Wani SP, Singh HP, Sreedevi TK, Pathak P, Rego TJ, Shiferaw B and **Shailaja Rama Iyer.** 2003. Farmer-participatory integrated watershed management: Adarsha watershed, Kothapally India, an innovative and upscalable approach. A case study. In Research Towards Integrated Natural Resources Management: Examples of Research Problems, Approaches and Partnerships in action in the CGIAR. (Harwood RR and Kassam AH, eds.). Washington, DC, USA: Interim Science Council, Consultative Group on International Agricultural Research, 123–147.

Wani SP, Sreedevi TK, Reddy TSV, Venkateswarlu B and **Prasad CS**. 2008. Community watersheds for improved livelihoods through consortium approach in drought prone rainfed areas. *Journal of Hydrological Research and Development*. 23:55-77.

Wani SP, Sreedevi TK, Rockström J and **Ramakrishna YS.** 2009. 'Rainfed agriculture – past trends and future prospects'. In: (Wani SP, Rockström J, Oweis T, eds.), Rainfed Agriculture: Unlocking the Potential. Comprehensive Assessment of Water Management in Agriculture Series. CAB International, Wallingford, UK, pp. 1–35.

Wani SP, Rockström J, Venkateswarlu B and **Singh AK.** 2011. 'New paradigm to unlock the potential of rainfed agriculture in the semi-arid tropics'. *In*: Lal R, Stewart BA. (Eds.), *World Soil Resources and Food Security. Advances in Soil Science*. CRC Press, United Kingdom, pp. 419–469.

Appendix I

List of Task Force Members

Sl. No.	Name	Designation	Organization Name	Place of the Organization
1	Dr. SP Wani (Chair)	Director	IDC, ICRISAT	Hyderabad
2	Dr Ch Srinivsa Rao	Director	CRIDA	Hyderabad
3	Dr. RK Bhatt	Director I/C	CAZRI	Jodhpur
4	Dr. PK Mishra	Director	IISWC	Dehradun
5	Dr. PK Joshi	Director for South Asia	IFPRI	New Delhi
6	Chandra A Madramootoo	Chair, ICRISAT Governing Board James McGill Professor and Dean	McGill University	Canada
7	Dr. K Palanisami	Consultant	IWMI	Coimbatore
8	Sri. Sandeep Dave	Joint Secretary	Department of Land Resources	New Delhi
9	Dr. Amita Prasad	Joint Secretary	Ministry of Water Resources	New Delhi
10	Sri. Pradeep Kumar	Commissioner (SPR)	Ministry of Water Resources	New Delhi
11	Sri NikhileshJha	Mission Director (NWM)	Ministry of Water Resources	New Delhi
12	Sri SK Srivastava	Chief Engineer, NWA	Ministry of Water Resources	New Delhi
13	Sri. HG Shivananda Murthy	Commissioner, Watershed Development Department	Govt. of Karnataka	Bengaluru
14	Smt. C Nagarani	Addl. Commissioner (IWMP), Rural Development	Govt. of Andhra Pradesh	Hyderabad
15	Smt. Anita Ramachandran	Commissioner, Rural Development	Govt. of Telangana	Hyderabad
16	Sri. B Nijalingappa	CEO	SLNA	Jharkhand
17	Dr. Girish Sohani	President	BAIF Development Research Foundation	Pune
18	Mr. Arvind G. Risbud	Executive Director	MYRADA	Bengaluru
19	Sri.Vishwa Mohan Upadhyaya	Commissioner, Panchayat & Rural Development Department	Govt. of Madhya Pradesh	Bhopal
20	Dr. R Anand Kumar	Executive Director, TWDA	Govt. of Tamil Nadu	Chennai
21	Mr. Anurag Bhardawaj	Director, Watershed Development Department	Govt. of Rajasthan	Jaipur
22	Mr. Biswanath Sinha	Associate Director	Sir Dorabji Tata Trust	Mumbai
23	MrAjit Jain	Jt. Managing Director	Jain Irrigation Systems Ltd.,	Maharashtra
24	Dr AvinashTyagi	Secretary General	International Commission on Irrigation and Drainage (ICID)	New Delhi
25	Dr Kaushal K Garg	Sr Scientist, IDC	ICRISAT	Hyderabad
26	Dr KH Anantha	Sr Scientist, IDC	ICRISAT	Hyderabad

Appendix II

Ex-ante analysis of different interventions under PMKSY.

Sl. No	Technology intervention	Total area (m ha)	Adoption per cent in ten years[1]	Parameter	Unit	Total area adopted in ten years	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total benefit (Rs in Crore)
1	Protected cultivation (rainfed system)	76	25	19	Mha	19	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.2	17.1	19	
	Benefit/ha/year (Alfisol)			132,000	Rs/ha/ year												
	Benefit/ha/year (Vertisol)			176,000	Rs/ha/ year												
	Average benefit/ha/year			154,000	Rs/ha/ year		29,260	58,520	87,780	117,040	146,300	175,560	204,820	234,080	263,340	292,600	1,609,300
2	Watershed area	76	50	38	Mha	38											
2.1	In-situ intervention	38	50	19	Mha	19											
2.1.1	Rice fallow	11.4	50	5.7	Mha	5.7	0.57	1.14	1.71	2.28	2.85	3.42	3.99	4.56	5.13	5.7	
	Chickpea yield/ha			800	Kg/ha												
	Market price (Rs/kg)			40	Rs/kg												
	Gross income, Rs/ha			32,000	Rs/ha												
	Cost of cultivation Rs/ha			10,000	Rs/ha												
	Net benefit, Rs/ha			22,000	Rs/ha		1,254	2,508	3,762	5,016	6,270	7,524	8,778	10,032	11,286	12,540	68,970
2.1.2	Rainy season fallow	2	50	1	Mha	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	
	Green gram/black gram yield/ha			1000	Kg/ha												
	Market price (Rs/kg)			40	Rs/kg												
	Gross income, Rs/ha			40,000	Rs/ha												
	Cost of cultivation Rs/ha			15,000	Rs/ha												
	Net benefit, Rs/ha			25,000	Rs/ha		250	500	750	1,000	1,250	1500	1,750	2,000	2,250	2,500	13,750

Continued

Ex-ante analysis of different interventions under PMKSY.

Sl. No	Technology intervention	Total area (m ha)	Adoption per cent in ten years[1]	Parameter	Unit	Total area adopted in ten years	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total benefit (Rs in Crore)
2.1.3	Other methods			12.3	Mha	12.3	1.23	2.46	3.69	4.92	6.15	7.38	8.61	9.84	11.07	12.3	
	Base crop yield			1500	Kg/ha												
	Yield after insitu interventions			1800	Kg/ha												
	Increased yield (Kg/ha)			300	Kg/ha												
	Av. Market price: Rs/kg			15	Rs/Kg												
	Net benefit (Rs/ha)			4500	Rs/ha		553.5	1,107	1,660.5	2,214	2,767.5	3321	3,874.5	4,428	4,981.5	5,535	30,443
2.2	Other income generation/Livestock activity/Community GW recharge etc.	38	50	19	MHa	19	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.2	17.1	19	
	Net benefit (Rs/ha)			3000	Rs/ha		570	1140	1,710	2,280	2,850	3,420	3,990	4,560	5,130	5,700	31,350
3	Irrigated area	65	50	32.5	Mha	32.5											
3.1	Water use efficiency																
3.1.1	Canal command area	21	50	10.5	Mha	10.5	1.05	2.1	3.15	4.2	5.25	6.3	7.35	8.4	9.45	10.5	
	Current water use efficiency			40	Percent												
	WUE after intervention			60	Percent												
	Area after intervention under irrigation			12.6	Mha	12.6	1.26	2.52	3.78	5.04	6.3	7.56	8.82	10.08	11.34	12.6	
	Additional irrigated area due to intervention			2.1	Mha												
	Current yield without irrigation			1500	Kg/ha												
	Yield with irrigation facility			3000	Kg/ha												

Continued

Ex-ante analysis of different interventions under PMKSY.

Sl. No	Technology intervention	Total area (m ha)	Adoption per cent in ten years[1]	Parameter	Unit	Total area adopted in ten years	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total benefit (Rs in Crore)
	Increased yield (kg/ha)			1,500	Kg/ha												
	Av. Market price: Rs/kg			15	Rs/Kg												
	Net benefit per season (Rs/ha)			22,500	Rs/ha		5,670	11,340	17,010	22,680	28,350	5,670	11,340	17,010	22,680	28,350	
	net benefit from two crop season (Rs/ha)																340,200
3.1.2	Groundwater irrigated area	44	50	22	Mha	22.0	2.2	4.4	6.6	8.8	11.0	13.2	15.4	17.6	19.8	22.0	
	Increased WUE			20	Per cent												
	Current yield (e.g., wheat, Rice)			3,000	Kg/ha												
	Yield with irrigation facility			3,600	Kg/ha												
	Increased yield (kg/ha)			600	Kg/ha												
	Av. Market price: Rs/kg			15	Rs/Kg												
	Net benefit (Rs/ha)			9,000	Rs/ha		1,980	3,960	5,940	7,920	9,900	11,880	13,860	15,840	17,820	19,800	
	net benefit from two crop season (Rs/ha)																217,800
																	2,311,813

[1] The adoption rates have been taken based on the practical experiences. The highest adoption rate in ten years is 50% for most of the technologies and 25% for protected cultivation only, respectively. These values of adoption rates are used for calculating the net benefits for a given intervention with appropriate adoption per year reaching up to the maximum adoption rate in ten years.

Appendix III

Case Studies

Selection of best water management practices in India

1. River linking (Trans-boundary)

1.1 Jalgaon River Linking Project: Demand-based Project through Citizen's Participation

The key problem:

In 2005, the Jalgaon district in Maharashtra state received scanty rainfall in comparison to most of the places across the state that was experiencing flood-like situations. During this period, the Jalgaon district received less than the average rainfall, i.e., only 15% by mid-July and 73% by end-October. Seven tehsils of Jalgaon district were largely affected due to the drought conditions. During these dry years, efforts were made to meet the water demand in terms of digging new bore wells and also through tankers. But such an approach involves high expenditure and is not sustainable. Moreover, this expenditure does not create any permanent asset. With frequent occurrence of droughts, rivers remained dry as there was no run-off generated; consequently, all water reservoirs were empty along with the depletion of the groundwater level. Where as in the neighboring district like Nashik, overflowing of the Girna dam was observed. Hence, the excess water from the Girna dam, which was otherwise going downstream, had the potential of being diverted to the water-scarce regions of Jalgaon. The planning is often supply-driven rather than demand-based. This drawback was attempted to be addressed through the Jalgaon River Linking Project.

The solution:

The local administration along with the involvement of the community designed the project and helped in conduction of the technical feasibility assessment. The local villagers willingly parted their land to enable the inter-linking of the rivers. It was strategized that the existing canals were to be used to the maximum extent possible. These canals were repaired and their capacities were enhanced by desilting and raising the embankment heights. The existing natural big drains, riverbeds, and channels were also used to a large extent and additional canals and channels were dug wherever required. The project was planned in such a manner that the natural contours and gravity would be fully utilized following the diversion of water. This was critical not only to keep costs and maintenance low and but also to impart sustainability to the project.

The impact:

- The drinking water problem was resolved for a population of about 8.5 lakh covering one municipal corporation, five municipal councils, and 123 villages.
- In total, around 700 medium, small dams, KT weir, village tanks, and percolation tanks were filled, and more than 16,000 water wells were recharged. It resulted in an additional storage capacity of 4,886 Mcft of water.
- The river-linking project helped in increasing the area under irrigation from 13,000 ha in 2005 to 30,000 ha in 2008. The total estimated benefits received by the agriculturists ranged between ₹ 25-30 crore annually.
- The increased water availability for drinking purposes has done away with the need for tanker water supply, implying a savings of about ₹ 9 crore per annum.
- This has also resulted in an increase in the water table in some tehsils in spite of receiving 35-45% less than average rainfall.
- Twenty six percent households reported their active participation in the execution of the links contributing to 2142 non-working days. Forty-two per cent people reported an increase in their employment opportunities. Fifty-seven percent people reported receipt of adequate drinking water. Fifty percent of the people are well aware of the river linking project. Eighty-one percent of the households surveyed are engaged in farming and 5% in agricultural workers.

Integration or inclusiveness:

In the case of Jalgaon, different funding sources were converged and utilized. Firstly, the Jalgaon Collectorate allotted funds to tackle problems in times of water scarcity. The Irrigation Department agreed to fund the initial project survey cost and provided technical assistance in making the project a reality. The high-powered committee of the Government of Maharashtra was convinced to allocate ₹ 2 crore from the scarcity fund for the novel river-linking project. The funding was also made available from the MPLADS and MLALADS schemes, as well as from various Municipal Councils.

Lessons learnt from the approach:

The involvement of these stakeholders meant that a strong platform was created for generation of the support from a wider audience. This project is a fine example of several different departments working together and pooling their respective strengths to achieve a common objective of addressing water scarcity.

The involvement of the citizens in the planning process allowed the potential benefits of the project to be disseminated among the people at large. In the process, they enhanced the commercial value of their land that was earlier considered as barren. The availability of water for irrigation on account of diversion of water resulted in increased land productivity. Further, the local people also participated in the project by being physically involved in the river-linking works. The monetary value of the local people's contribution would have far exceeded the government contribution of ₹ 2 crore.

The way forward:

If such kind of cost-effective and citizen-friendly small projects are implemented by considering a few districts as a unit depending upon various technical factors, i.e., alignment, topography, natural drainage networks, etc, much better results can be achieved. The collective action and convergence of different schemes is essential to address the complex issues of natural resource management.

Name of the project: Jalgoan River Linking Project

Key partners: Jalgoan Collectorate, Department of Irrigation, Municipal Corporation/Councils, MP/MLA

Project duration: 2005

Source: http://www.indiaenvironmentportal.org.in/files/GKC_RiverLinking_BestPractice[1].pdf

2. Traditional water harvesting

2.1 Productivity enhancement through traditional rainwater harvesting (*Khadin*) in Jodhpur, Rajasthan

The key problem: The Baorali-Bambore watershed in eastern Rajasthan is experiencing low and erratic rainfall (300-350 mm) leading to water scarcity, frequent crop failures, low productivity, and drought.

The solution: The detailed topographical survey of the area was carried out. Three *khadin* farms of 3 ha, 6 ha, and 10 ha have been developed in a sequence in the watershed for runoff farming that involves growing crops on the stored soil profile moisture. The catchment to command area of 12:1 has been maintained. The upper *khadin* covering 3 ha of agricultural field has been constructed for rainwater harvesting from the upland catchment area. A masonry waste weir has been designed at the lowest elevation for regulation of the surplus water in *khadin*. A sluice made with a control gate has been provided in the upper and middle *khadin* for draining out standing water in the *khadin* before sowing of the winter crops. This available water in *khadin* will be utilized for pre sowing irrigation outside the *khadin*. In the *khadin* constructed at the lower reach, a loose stone waste weir acting as a surplus arrangement to spill out excess runoff has been constructed. The catchment to command area has been optimized for better storage and management of the rainwater. The *chain* f arms have been rigorously built and interwoven to raise crops even during severe drought years.

The Impact: During the 2002 drought year (32.5 mm of rainfall), the effective rainfall that contributed runoff in *khadin* was only 11.6 mm. Nearly 35% (4 mm) runoff from the upland catchment was harvested and stored in *khadin* farm that enriched the soil profile moistures. The sorghum (CSV 10) that is considered to be a fodder crop was grown on the stored profile moisture in *khadin* (Figure 1). The average fodder yield of 95 q ha^{-1} in *khadin* has been achieved whereas in the other parts of watershed nothing could be grown due to moisture limitation. The gross income of the farmers has been raised to ₹ 28,500 ha^{-1} with the sale of the fodder @ ₹ 3 per kg. During the years of normal and good rainfall, the farmers are harvesting excellent crops of mustard, wheat, and horse gram in *rabi* season on conserved moisture of the *khadin*. This suggests that *khadin* system of water harvesting and moisture conservation is effective even during severe drought years for the sustenance of the farmers belonging to the arid regions.

Integration or Inclusiveness: Twelve farmer families resided in the *khadin* area. Farmers' participation was ensured from the beginning of the planning and implementation process. Regular communication channels were established with frequent visits.

Lesson learnt from this approach: The key factors that governed the success of *khadin* system was proper selection of the site for construction of *khadins*, accurate hydrological analysis of data for rainfall, runoff and other processes for estimation of available runoff, farmers' trust and full cooperation during the initial phases, and subsequent selection of proper crop varieties followed by recommended package of practices.

Figure 1. a) Water harvested in khadin during the monsoon period; b) Sorgum cultivation in khadin using residue soil moisture.

The way forward: Since water is a scarce commodity in arid areas and *khadin* is a location specific technology, such technology can be scaled up in large areas in arid zone based on the detailed topographical survey of the potential sites. The remote sensing technology could be helpful in optimization of the land resources.

Name of the project: Watershed Management Technology in Hot Arid Region (Baorli-Bambore Watershed)

Key partners: Central Arid Zone Research Institute- Jodhpur, Project funded by ICAR-New Delhi under NATP

Project duration: 1998-2004

Compiled by: RK Bhat, DK Painuli and RK Goyal, Central Arid Zone Research Institute (CAZRI)

2.2 Addressing water scarcity through strengthening of the traditional water harvesting *Haveli* system in Bundelkhand region, Central India

The problem:

The Bundelkhand region comprises of 13 districts of Madhya Pradesh and Uttar Pradesh covering approximately an area of 70,000 square kilometers with 21 million people, nearly the size and population of Sri Lanka, and is facing acute water scarcity. The rainfall is highly erratic, both in terms of amount and distribution over the time. Long-term weather data monitored at Jhansi station showed that the annual average rainfall of this region has decreased from 950 mm between the years 1944 and 1973 to an average of 847 mm between the years 1974 and 2004 (Figure 1). This reduction was mainly due to the decreased number of low (0-10 mm) and medium rainfall (30-50 mm) events. Similarly, the total number of rainy days in a year also decreased. The repeated occurrence (5-6 times) of dry spells longer than 5–7 days during the monsoon season are very common in these areas. Where as, 10–15 days of longer dry spell may also occur during the monsoon period.

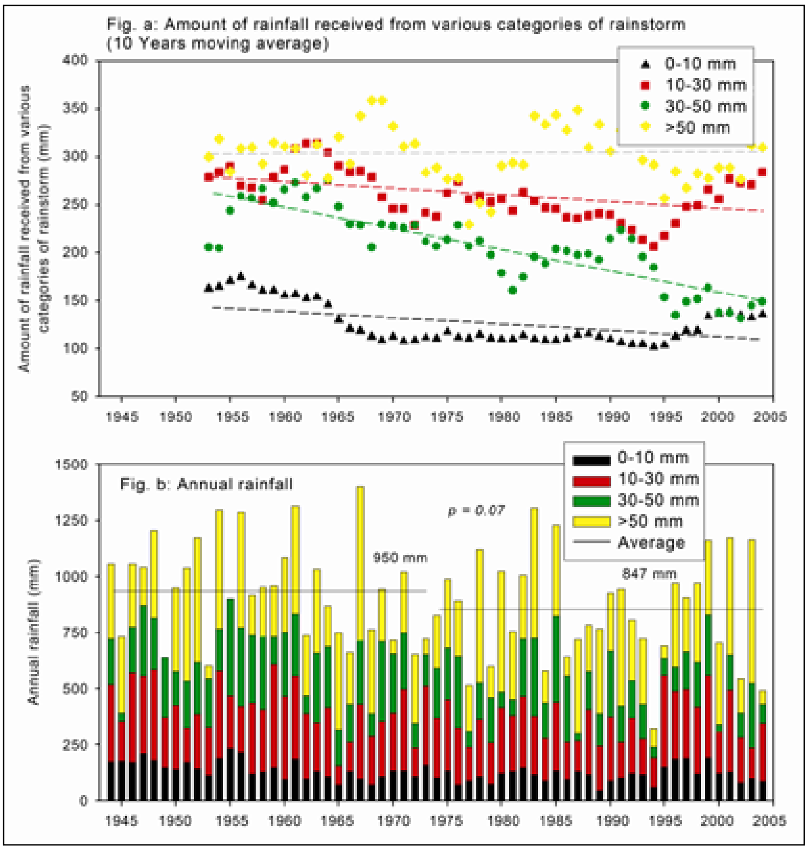


Figure a. Amount of rainfall recevied from various categories of rainstorm (10 Years moving average).

Figure 2. Haveli renovation in Parasai-Sindh watershed; Masonry drop spillway (rectangular weir) and embankment along with core wall was constructed in 50 m breached area. Water harvested in Haveli during the monsoon period.

Agriculture and allied sectors are the main sources of livelihood for the rural people in this region. The crop and livestock productivity are very low and large yield gap exists to be harnessed. The rural communities are largely dependent on the groundwater resources for domestic and agricultural use. Due to the hard-rock geology, the groundwater recharge mainly takes place in shallow and unconfined aquifers that is characterized by poor specific yield. The water level in open/dug wells depletes at a very faster rate after the monsoon, and the communities suffer from water scarcity especially in summer. The region has been experiencing severe drought conditions in last six of ten years. The women and girls were the worst affected sections of the society, as they were spending significant time and energy to collect water for the domestic use.

The solution:

Historically, water harvesting called as "*haveli* system" was evolved to overcome the water scarcity situation in Bundelkhand region. This system was developed during the period of Chandelas and Bundelas (nearly 400 years back). The earthen bunds across the stream were built to impound water during the monsoon. The bunds were further strengthened through plantation of trees like ber and butea. The water is harvested during the monsoon period that largely recharges open wells and also serves as an irrigation source during the critical stage for *kharif* crop (eg, groundnut, pulses, etc.) in the surrounding areas of *Haveli*. The impounded water is drained-out during the month of October and the *Haveli*-bed is used for cultivating *rabi* crop (e.g., wheat and chickpea). The drained water from *Haveli* tanks are also used for the pre sowing irrigation. Wheat and chickpea are generally cultivated in *Havelis* using the residual soil moisture. Over the period, *Havelis* have become defunct due to various reasons such as damaged outlet, leakage in embankment, excessive siltation, etc. Despite the number of ongoing government programs on water resources development and management (e.g., watershed development) in the region, these structures were neither repaired nor rejuvenated.

Site of learning:

The Parasai-Sindh watershed project comprising of three villages and covering nearly 1,250 ha, was selected for developing a benchmark site in the Jhansi district. In this watershed project, *Haveli* that was historically constructed at very upstream site was defunct due to the damaged outlet and washing out of nearly 50 m of the embankment. Mr. Kalyan Singh, a resident of Parasai village shared that this structure is nearly 300 years old. Since 2012, ICRISAT along with its national partners ICAR-Central Agro-Forestry Research Institute (CAFRI), district administration, government of Uttar Pradesh, and local community started the implementation of the watershed interventions in Parasai-Sindh area with support of Cococola India Foundation. The scientific team of ICRISAT and ICAR-CAFRI along with the local community conducted the inspection of the traditional structure and reached at a decision of its rejuvenation through a consortium project. A drop spillway (rectangular weir) outlet was constructed to drain excess runoff during the rainy season. The weir was constructed at a height of 1.45 m from the bed level. The earthen embankment along with core wall was constructed in 50 m breached area (Figure 2). To control seepage, 147 m stone masonry wall was constructed along the embankment of *Haveli*. Submergence area of the structure is about 8.0 ha with harvesting capacity of 73000 cum.

The impact:

Due to the rejuvenation of *Haveli*, nearly 200000 cum runoff are now being harvested every monsoon season that completely resolved the water scarcity issues of the village. The average of groundwater table increased on an average of 2.5 meters varying from 2.0-4.0 meter as per the toposequence. This has increased the cropping intensity by 50% in upper reach of watershed especially during post the monsoonal season. The productivity of post-monsoonal crop especially wheat has doubled. The wheat yield before the watershed interventions was in range of 1500-1800 kg ha^{-1}. Prior to the intervention, despite the good crop establishment, there was high chance of crop failure due to the depletion of water resources by the end of January-February that coincided with the flowering or milking stages. Supplemental irrigation was also not possible due to the drying wells. After the *Haveli* renovation along with construction of few more water harvesting structures at the downstream site, the farmers started harvesting wheat with yield ranging from 2500-3500 kg ha^{-1} that assisted in significant upsurge in their income and livelihood. Further, the farmers have shifted cropping pattern from low water requiring crops (chickpea and mustard) to high-value vegetables and wheat crops. Because of improved yield of wells in upper reach, 40-45 ha fallow land was also brought under cultivation from the year 2013 onwards. Fodder availability has increased significantly due to which milch animal population has increased by 30% (nearly from 900 to 1200 buffalos). The *Haveli* renovation along with number of watershed interventions in Parasai-Sindh watershed has led to an enhancement of the average annual family income from 50,000 INR (830 USD) to 125,000 INR (2080 USD) in a short span of three to four years.

Way forward:

Under the changing climatic conditions and decreasing annual rainfall, Bundelkhand is expected to experience upcoming future challenges of drought. The long-term weather data of Jhansi indicated that the medium duration rainfall events decreased leading to reduced annual rainfall by 100 mm in the last 30 years. With the further continuation of such trends, Bundelkhand is expected to face frequent occurrence of dry years and dry-spells of longer duration. Such climatic changes may adversely affect the hydrological cycle and water resources, especially the groundwater availability in Bundelkhand, which is the only source of water for domestic and agricultural use in the region. In such situations, rejuvenation of traditional water harvesting system in entire Bundelkhand region could be a suitable adoption strategy and long term solution to address the water scarcity issues and strengthen the rural livelihood.

Name of the project: Improving Management of Natural Resources with Sustainable Rainfed Agriculture.

Key partners: ICRISAT, ICAR-CAFRI, Government of Uttar Pradesh (GoUP), Coca-Cola India Foundation

Project duration: 2012-2016

Compiled by: Ramesh Singh, OP Chaturved, RK Tewari, Inder Dev, RP Dwivedi, RH Rizvi and KB Sridhar (ICAR-Central Agroforestry Research Institute (CAFRI); Kaushal K Garg and Suhas P Wani (ICRISAT).

3. Watershed management

3.1 Adarsha watershed, Kothapally, Telangana State, India (800 mm rainfall)

The problem:

In the year 1998-99, Kothapally village in Shankarpally mandal of Ranga Reddy district in Telangana (earlier it was within the territory of Andhra Pradesh state that was later bifurcated into two states in the year 2014) was one of the villages with least development, no transport facilities, and 80% of 462 ha of rainfed agricultural land growing only one crop per year. The main crops grown were cotton, maize, sorghum, and pigeonpea with 1 to 1.5 t ha^{-1} productivity of sorghum and maize, and 200 kg ha^{-1} of pigeonpea. All the 62 open wells dried from January onwards and village women had to travel 2 to 3 km to fetch drinking water, from February till the arrival of monsoon rains during June-July. Milk production from the livestock was insufficient for selling. Small farm holders migrated to the city for improving their livelihood during the off season.

The solution:

The wilt tolerant high-yielding pigeonpea cultivar was grown on the broad bed and furrows (BBF), as an entry point for the community mobilization. During the first season of pigeonpea yield that increased to 600 kg ha^{-1}, which benefitted the farmers with additional income of ₹ 6000 ha^{-1} in 1999. The tangible economic benefit to the small farm holders triggered the collective action, and subsequently the common activities like facilitation of rainwater harvesting structures benefitting the community. In 1999, the first earthen check dam near the village was constructed which benefitted the nearby wells, provided drinking water for the animals, and also for washing clothes. The low-cost rainwater harvesting (RWH) structures (43), masonry structures (14), sunken pits (37) as well as gully control structures (97) throughout the topo-sequence, by following ridge to valley approach, and open well recharging pits (39) in the watershed were constructed. The soil nutrient status mapping and soil test-based fertilizer recommendations, introduction of improved cultivars, integrated pest management (IPM), vermicomposting, Glyricidia plantation on the bunds to generate N rich organic matter, avenue plantation, nursery raising, fodder production from the wasteland, and livestock breed improvement through artificial insemination centre in the village were undertaken in participatory mode, and the farmers contributed in cash for each activity undertaken to ensure the ownership of the farmers.

The Impact:

The groundwater availability increased from 3.5 m to 6.0 m due to various soil and water conservation interventions (Figure 1). Due to the increased availability of water resources, the entire watershed area transformed from degraded to productive land mass. The cropping intensity increased from 85% to 150%, and large number of farmers shifted from low water requiring crops to high-value crops (e.g., Bt. Cotton and vegetables). In addition, the environmental benefits such as improved water quality (pesticide residues free), increased water availability round the year, reduced runoff (30-40%), reduced soil loss (from 10 t ha^{-1} to 2 t ha^{-1}) (Figure 2&3), increased greenery cover as assessed by the satellite imaging (the IRS-IC, ID LISS-III and NDVI), and associated increase in carbon sequestration through tree cover as well as increased agricultural production was observed. Water is available in the open wells all around the year and the women get the drinking water through taps using bore well.

The most visible impact in Kothapally project has been marked by the boost in the confidence of the farmers, and particularly in the women, who feel that they can cope up with the challenges emerging out due to the climate change. During2014, in spite of deficit rainfall, the farmers have grown their crops using the available water. They are busy delivering 600 liter milk every day at the computerized milk collection center set up by the Reliance group, and about 500 liters per day at private milk collectors center. The selling of milk alone adds up to ₹ 40,000 per day to the village income. With the help of SABMiller, the women group has started a new initiative to provide spent malt as quality feed for milch animals and as a

Figure 1. Post monsoonal water level in one of the selected wells of Adarsha watershed, Telangana. a) before, and b) after the watershed intervention.

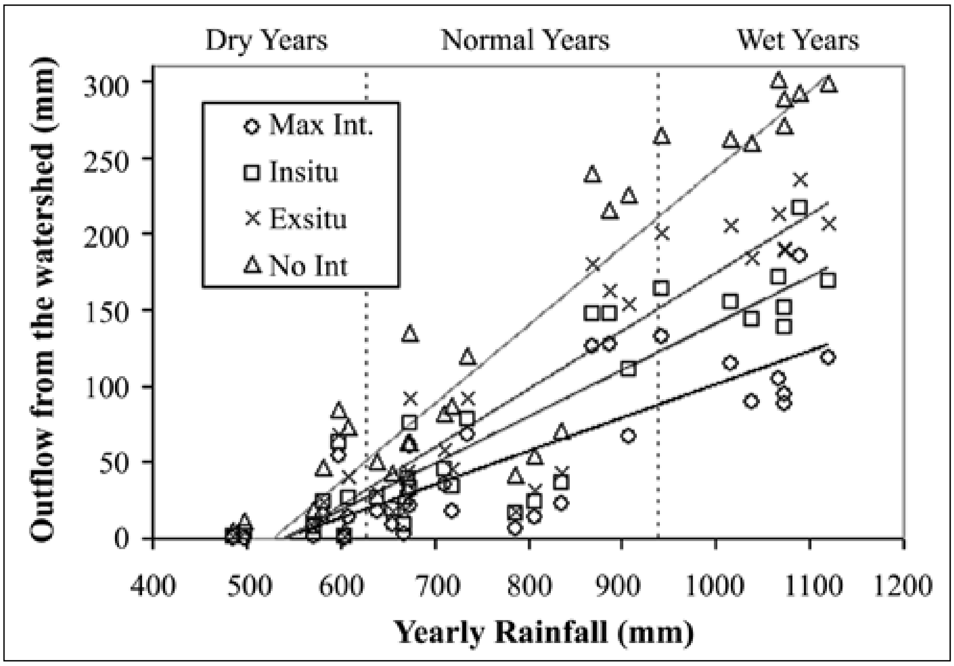


Figure 2. Rainfall-Runoff relationships for the four different water management scenarios in a micro watershed project at Kothapally located in the SAT zone of Southern India.

result the productivity of milk per animal per day has increased by 1.5 liter with improved fat content and is generating ₹ 9710 per day additional income in the village. The village is getting an increased net income of around ₹ 3 lakh per month with an average net income of ₹ 5500 per family from this enterprise.

The increased water availability has transformed the one season agriculture in the village to two - three crops, and has also moved from maize and sorghum to Bt cotton and high-value vegetables production. The average crop yield of maize has increased by 2.2 to 2.5 times (3.8 t ha^{-1} as against 1.5 t ha^{-1} in farmers' practice). Intercropped maize-pigeonpea with improved management produced 6 t ha^{-1} compared to 2.9 t ha^{-1}.The pigeonpea yields increased to 900 kg ha^{-1} against 200 kg ha-1 in the year 1998. Similarly, the hybrid cotton was replaced by BT cotton with increased productivity of 7.1 t ha^{-1} as compared to 2.1 t ha^{-1} in the year 1998. The average household income from crop production activities within and outside the watershed was ₹ 15400 and 12700, respectively. The respective per capita income was ₹ 3400 and 1900. The average income from agricultural wages and non-farm activities during the year 2002 was ₹ 17700 and 14300 within and outside the watershed, respectively. The farmers started growing more diversified crops

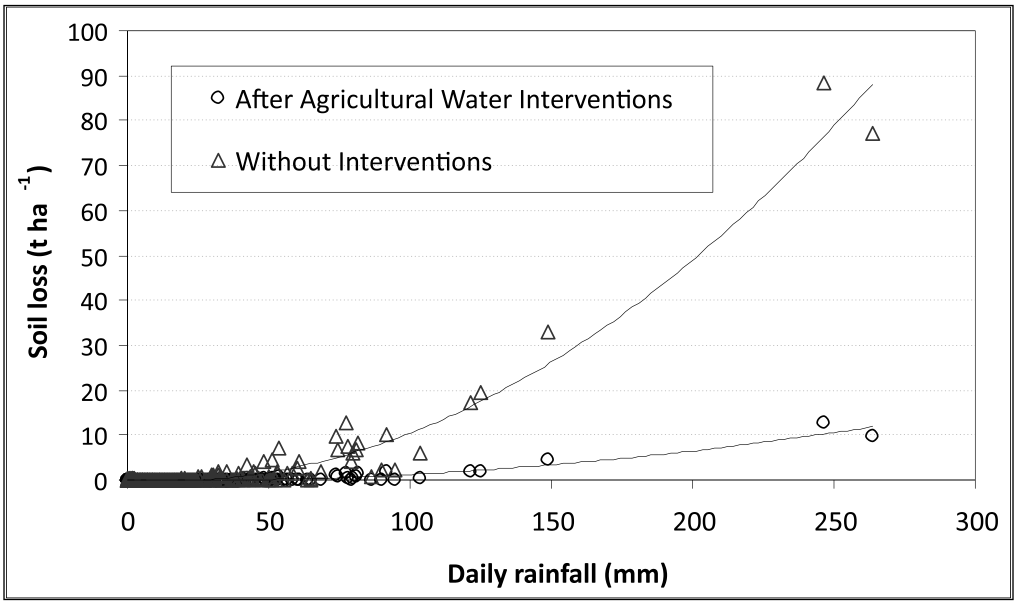


Figure 3. Impact of agricultural water interventions on soil loss in Kothapally watershed, Telangana. Average annual rainfall of the watershed area is 800 mm.

as well as diversified their income sources through livestock rearing. As a result, the farmers' average incomes increased by three folds in the year 2010 compared to ₹ 25000 in the year 1998. In comparison with the non-watershed farmers, the income during the drought year of 2002 was 1.5 folds higher and the villagers in Kothapally did not migrate for livelihood sustenance. The watershed development has contributed to improved resilience of agricultural income despite the high incidence of drought during the year 2002 in the watershed areas. The drought-induced shock caused reduction in the average share of crop income in the non-watershed area from 44 to 12%.This share remained unchanged at about 36% in the watershed area.

Integration or inclusiveness:

This was the first of its kind initiative that included livelihood support approach by involving different partner organizations who were dealing with wide variety of areas, and designed implementation plan for drought proofing with improved technologies based on the severity of water scarcity, more rainfed area, low crop yields, poverty, and willingness of the community to work together. ICRISAT brought together the partners along with the Government of Andhra Pradesh (GoAP), MV Foundation, Central Research Institute for the Dryland Agriculture (CRIDA), and the National Remote Sensing Agency (NRSA now refereed as NRSC).

Lessons learnt from this approach:

The integrated approach combines the progresses in the field of productivity, sustainability, and impact on food security. There are two key points to note: first, agriculture should be the clear focus of a possible goal related to the food security and environmental sustainability. Second, small farm holders should be covered under the program not only through focus on the land productivity but also through a broader agenda of sustainability and building system resilience.

The way forward:

The small farm holders in these regions have shown potential to bridge the large yield gaps by actively adopting to the change, and they continue to do so; however, these efforts need to be supported by enabling policies that will help them adapt to the on-going changes in a sustainable way, in order to achieve sustainable livelihoods and maintain important ecosystem services. The national policies need to help support and secure land tenure, access to resources and empower women for promoting farming in these regions. The same is true for the extension services that support farmers in achieving sustainable farming practices by providing information in areas such as appropriate use of external inputs including seeds, fertilizers, and pesticides. The innovative technologies and traditional knowledge need to be carefully integrated to increase and restore resilience along with better access to markets through collective cooperation.

Name of the project: Improving Management of Natural Resources with Sustainable Rainfed Agriculture

Key partners: ICRISAT, Government of Andhra Pradesh (GoAP), MV Foundation, Central Research Institute for the Dryland Agriculture (CRIDA), and the National Remote Sensing Agency.

Project duration: 1999-2004

Compiled by: Kaushal K Garg, KH Anantha and Suhas P Wani (ICRISAT)

3.2 Impact of watershed interventions on water resources availability and rural livelihood in Garhkundar-Dabar watershed of Bundelkhand region, Central India

The Bundelkhand region of Central India is a hot spot of water scarcity, land degradation, poverty, and poor socio-economic status. The large numbers of inhabitants in the Bundelkhand region are dependent mainly on the livestock-based activities. Approximately 33% of the total geographical area is covered under degraded forest, grazing land, and waste land. The undulated topography, poor groundwater potential, high temperature, poor and erratic rainfall, has led to poor agricultural productivity (0.5-1.5 t ha^{-1})in this region. Most of the areas are single cropped and completely under rainfed conditions.

In 2005, the Central Agroforestry Research Institute (CAFRI), Jhansi (the then NRCAF), Indian Council of Agricultural Research (ICAR) in partnership with the selected farmers from the Garhkundar-Dabar (GKD) watershed (850 ha geographical area) region led to the implementation of various agricultural water management interventions at field and watershed scale (Figure 1). The main purpose of developing GKD watershed was to establish a learning site for the farmers', rural community, researchers, and other stakeholders (development agencies and policy makers) to understand the impact of the integrated watershed management interventions in Bundelkhand region that experiences frequent drought. The rainfall is highly erratic, both in terms of total amount and its distribution over time. The large portion of the watershed was in degraded stage, and poor in organic matter and nutrient status. This watershed is surrounded by elevated hills and associated with agricultural areas in the valley portion. Nearly 30% of the watershed area is under agricultural use and rest is covered by degraded forest, wasteland, and scrubland. Soils in the upstream areas are excessively eroded and relatively shallow. The geology of the study area is dominated by hard rocks with poor transmissibility, and shallow dug wells of 5 to 15 m depth are only primary source of water for the domestic and agricultural use in this region.

The innovation:

Several in-situ and ex-situ interventions were implemented under the integrated watershed development program in GKD watershed. The most common in-situ interventions were field bunding, contour bunding, and cultivating crop across the slope, which harvests surface runoff, allowing more water to percolate and dispose excess runoff safely from the fields. The field bunding was done in 40 ha land area (15% of the agricultural land) and contour cultivation was promoted in rest of the agricultural land in this watershed. This practice created an opportunity to accumulate surface runoff along the contour line, and also protected soils from the erosion. The building check dams and low-cost gully control structures on the stream network (ex-situ practices) reduced the peak discharge, runoff velocity, and led to harvesting of a substantial amount of runoff in watershed that resulted in increased groundwater recharge. At the same time, these structures trapped the sediment that protected the river ecosystem. Following ridge to valley treatment, total nine check dams were constructed, including one in the control watershed, having

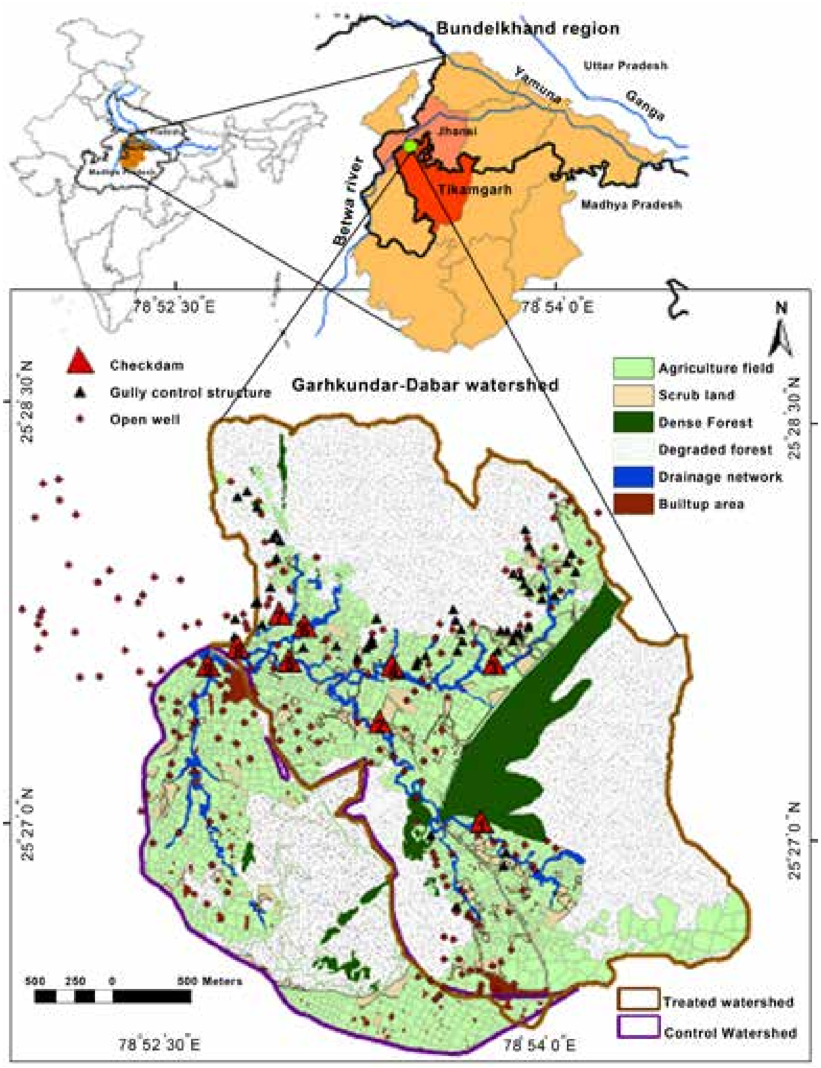


Figure 1. Location of the Bundelkhand region in northern India and important rivers; zoomed map shows stream networks, major land use, location of wells, check dams, and gully control structures in Garhkundar-Dabar watershed and near-by non-treated (control) watershed.

storage capacity between 1000 and 6500 m3. 150 low-cost gully control structures (called gabions locally) of 30-100 m3 capacity; and 15 drainage structures for safe disposal of excess water from agricultural fields were constructed. In total,35000 m3 of water storage space (~ 40 m3/ha) was developed in the watershed. The water in the check dams was directly for the irrigation and also served as the sites for artificial groundwater recharge. Other than soil and water conservation measures, focus on productivity enhancement through crop diversification and intensification, introduction of agroforestry system, introduction of improved seed variety, agronomic practices, and balanced use of chemical fertilizers were also initiated.

The impact:

Integrated watershed development interventions significantly changed the different hydrological components in GKD watershed. Due to the implementing IWD interventions, there was reduction in the surface runoff (20-35% of the rainfall), and increased groundwater recharge (8-10% of rainfall) and ET (55-70% of rainfall). On an average, 4.0 m difference in the hydraulic head (difference in water table) was recorded in case of open wells before and after the monsoon period. Despite more pumping and groundwater use, the hydraulic head in treated watershed was found approximately one meter higher compared to the control watershed through-out the year. The water table in the downstream wells are found equal or relatively higher than the control watershed but usually recorded lower as compared to the treated watershed. This indicated that upstream water harvesting did not have any adverse effect on the groundwater availability. The role of water harvesting structures such as check dam was found very important in GKD watershed. Total of eight check dams of 1000 to 6500 m3 created nearly 24800 m3 of storage space in the treated watershed. Our analysis showed that these structures could harvest more than eight times of the total storage capacity during the monsoon period. Moreover, the average annual soil loss measured from the treated watershed was 1.5 to 2.5 t ha-1 compared to 5.5 to 7.5 t ha-1 in the controlled watershed.

Figure 2 showed percentage of agricultural area under different cropping system grown in the treated and control watersheds between the years 2003 and 2011. With the increased availability of surface and groundwater resources, the cropped area increased drastically. About 95% of the agricultural land was cultivated largely with black gram and sesame during the monsoon; and 70-90% with wheat during post-monsoon that resulted into 190%of cropping intensity (double compared to the control) between the years 2009 and 2011. In the recent years, the areas under chickpea, mustard, and non-edible oil seeds were predominately replaced by wheat in the regions of treated watershed that is relatively more water demanding but economically remunerative and an assured crop. On the other hand, no significant changes were found in the cropping pattern and intensity in the control watershed compared to the base year (2003). Moreover, IWD interventions with improved crop management enhanced the crop yield by 30 to 50% depending on variety of the crops and cropping season. The average annual income generated from the treated watershed was ₹ 27500 ha-1 compared to ₹ 11500 ha^{-1} in the control watershed. The benefit-cost (B:C) ratio in the year 2009 exceeded one (>1.0) indicating four years of payback period on the invested capital.

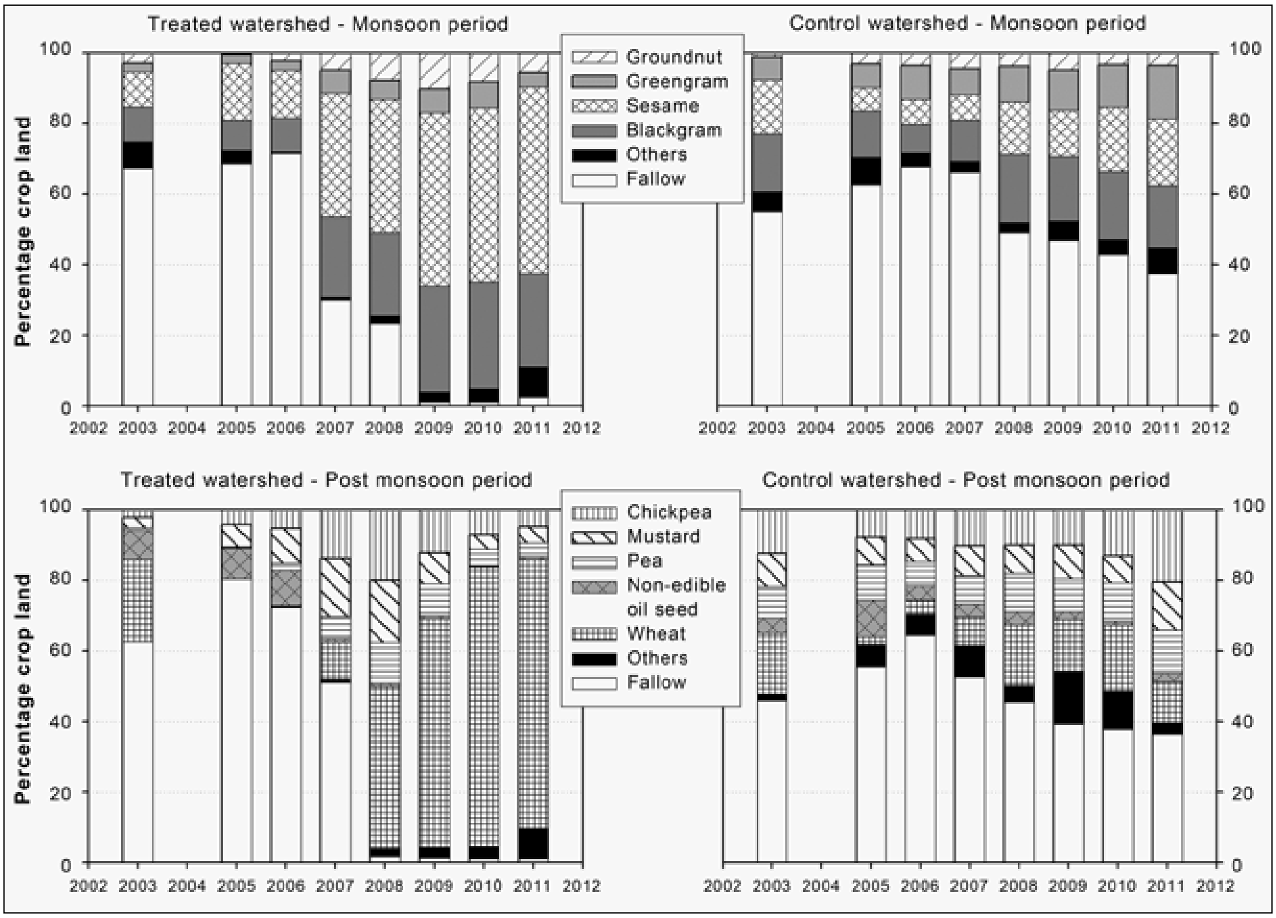


Figure 2. Change in the cropping pattern from year 2006 to 2012 during monsoon and post-monsoon period in the treated and control watershed regions.

Compiled by: Ramesh Singh, OP Chaturvedi, RK Tewari, SK Dhyani, RP Dwivedi and RH Rizvi [ICAR-Central Agroforestry Research Institute (CAFRI)], Jhansi, Uttar Pradesh.

3.3 Rejuvenating monsoon fallow areas through integrated watershed management in Raisen district, Madhya Pradesh

The key problem:

The Padarlya watershed is situated in Silwani tehsil of Raisen district in Madhya Pradesh. This watershed comprises of six villages viz., ChorPipliya, Rampura, DungariyaKhurd, Siyalwada, Gaganwada, and Padariya Kalan. The total area under the watershed is about 1736 ha (Figure 1). The mean annual rainfall is about 1050 mm. The watershed region predominantly consists of black soils. The total population in the Padarlya-Siyalwada watershed is 2821 (511 households). At the start of the watershed project in the year 2010, about 85% farmers were poor. The agricultural productivity was very low at 1.2-1.4 t ha^{-1}; also large areas were kept monsoon fallow leading to high land degradation and unsustainable agriculture. This watershed project has been implemented by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) along with its partners: Bhopal Yuwa Paryavaran Shikshan and Samajik (BYPASS) sansthan, Madhya Pradesh, Government department of agriculture, Raisen, Government department of animal husbandry, Raisen, and Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Indore.

The solution:

All the activities were undertaken in participatory mode with the community. The communities were involved from the beginning with constraint identification, prioritization of interventions, mode of implementation, monitoring and evaluation, and impact assessment for all the interventions in the watershed region. The community contributed their share along with the Ministry of Rural Development funded watershed project. Some of the key interventions implemented during the years 2010-15 at the watershed are:

- Broad-bed furrow and other *in-situ* soil and water management systems for improving drainage, and *in-situ* soil and water conservation (Figure 2).
- Land smoothing, field and community drains for safe disposal of excess runoff.
- Low-cost water harvesting and groundwater recharging structures (Figure 2).
- Monsoon fallow management by taking both rainy and post-rainy season crops.
- Improved farm implements.

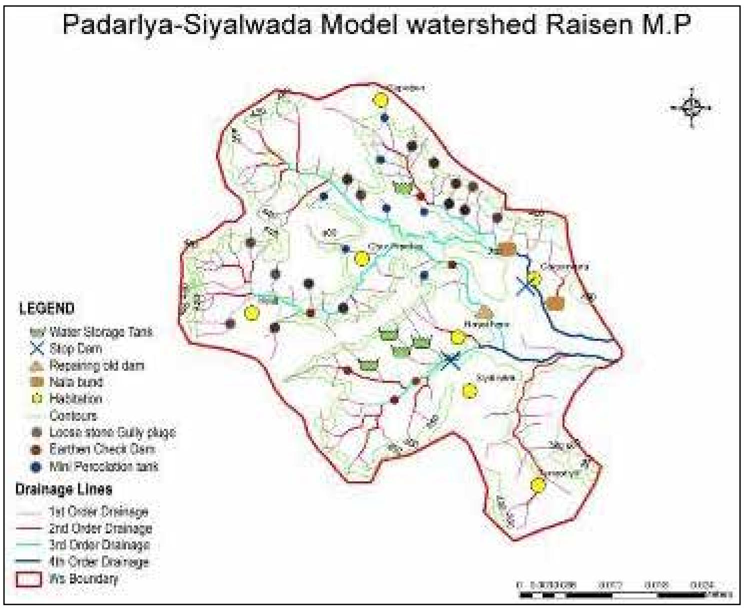


Figure 1. Map of Padarlya watershed region

- Improved irrigation methods viz., drip, sprinklers, and surface irrigation systems.
- Improved crop varieties of soybean, chickpea, groundnut, pigeon pea, and maize.
- Soil test-based balanced fertilization.
- Cultivation of high value crops viz., vegetables and horticulture products (Figure 3).
- Fodder production was taken up in 45 ha.
- Afforestation in watershed areas (50 ha).
- Income generation activities for women viz., setting of shops, tailoring, atta chakki, vermicomposting,and others (Figure 4).
- Livestock development.
- Capacity building through improved agricultural practices and income generation activities.

The impact

Due to the various *in-situ* and *ex-situ* soil and water management interventions, the availability of surface and groundwater increased by 2.5 times. Even in low rainfall year, the surface and groundwater availability in the watershed was adequate. The multi-faced impact of Padarlya watershed is shown in Figure 4. The income generating activities taken up for the women has brought positive changes in their lives. The number of women directly involved in the livelihood activities increased by seven folds. One of the key impacts of this watershed is on the management of the monsoon fallow areas which is prevalent in this region.

Figure 2. Various in-situ and ex-situ soil and water management interventions at Padarlya model watershed, Raisen, MP.

Figure 3. Cutivation of high value crops (vegetables).

Figure 4. Income generating activities for a sustainable livelihood (women empowerment).

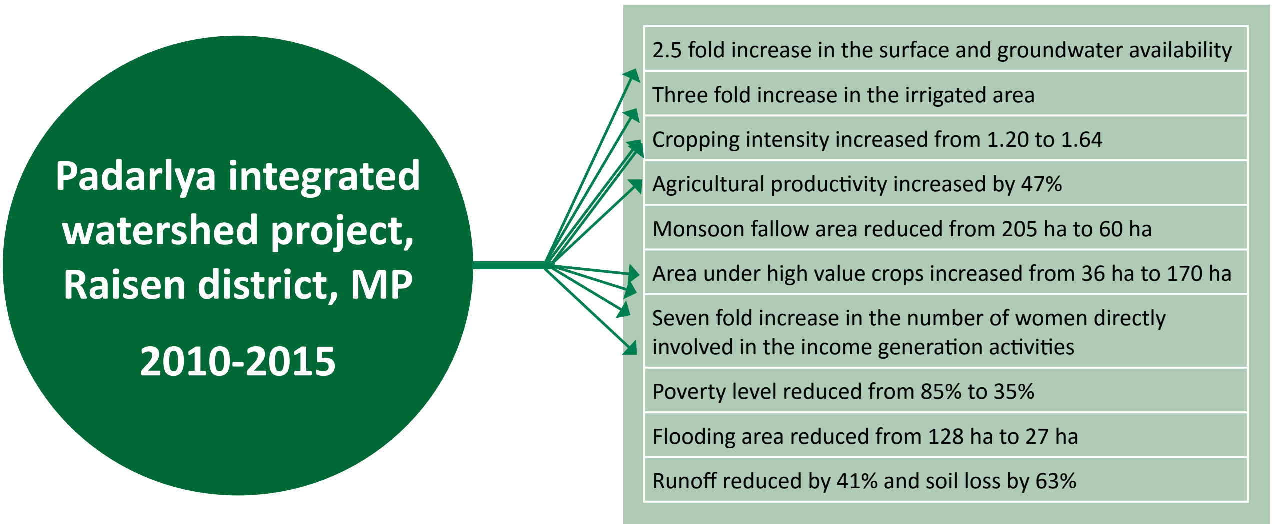


Figure 5. Multi- faced impact of Padarlya watershed project.

The dryland agriculture in Madhya Pradesh with medium to high rainfall vertisols areas has a vast potential to bridge the yield gap between the yields of the current farmers and the achievable potential yields. ICRISAT model of integrated watershed management has shown high potential for poverty alleviation and controlling land degradation. It has rejuvenated the degraded lands, enhanced agricultural productivity, improved rural livelihoods and incomes, decreased poverty of rural poor, and improved the environment quality.

Integration or Inclusiveness:

The tangible economic benefits to large numbers of farmers was achieved through increasing the productivity on individual farms through implementation of best bed management options on in-situ rainwater management, and its efficient use with improved crops/cultivars and nutrient management options. This approach led to the participation of a large number of farmers in the watershed development program as they derived good economic benefits from the productivity enhancement activities from the first cropping season itself. The community based soil and water management interventions on runoff harvesting and groundwater recharging, brought the community together to reap the benefits of the increased surface and groundwater availability, and cultivation of high value crops. The holistic approach which not only included agriculture but also animal husbandry and income generation activities helped in the improvement of livelihood of the landless farmers, women, and other vulnerable community members. The equity and gender concern regarding the women and other vulnerable groups was brought to the fore front of the watershed planning and execution. A fair representation (minimum 50%) of women and vulnerable groups in the decision making committees was made non-negotiable. For such group targeted interventions, the institutional support and financial allocations were considered as the integral part of this integrated watershed program.

Lessons learnt from this approach:

Some of the key learning about the factors that contributed significantly to the success of this approach for management of watersheds are:

(i) Technological interventions: Implementation of advanced technologies led to an increase in the productivity, and income, and gave tangible economic benefits such in-situ and ex-situ soil and water management systems, which is addressed by both moisture conservation as well as disposal of excess runoff. This has led to higher crop yields, low-cost water harvesting, and groundwater recharging structures resulting in cost savings and better equity, soil test based nutrient application including micronutrients, innovative monsoon fallow management system leading to higher cropping intensity and cultivation of high value crops (vegetables).

(ii) Other factors: Interventions targeted to meet the community needs (demand driven), linkage to market, quality capacity building, and consortium approach for the holistic implementation of watershed, targeted activities, and funding for women and vulnerable groups, and establishment of effective and strong local CBOs.

The way forward:

The innovative integrated watershed management model developed and implemented by ICRISAT along with partners could be effectively implemented to manage 14 million ha of deep Vertisol areas in Madhya Pradesh. Once fully implemented this could result in additional agricultural production of 9.5 million tons per annum, with reduced soil loss of 32 million tons per annum and downstream flooding areas by 0.8 million ha. With limited project budget, efforts are being made to sensitize and bring more awareness among the senior government officials, local NGOs, and other organizations about the possible benefits of this approach for the management of Vertisols in Madhya Pradesh. At small scale, this model is already being implemented by some local NGOs and other project partners at few locations in Madhya Pradesh. To scale up this watershed model in the entire region will require sustainable budget for the development work and implementation of other interventions. In the first phase, this approach could be implemented in 2-3 districts of Madhya Pradesh covering the entire area. After 2-3 years, this could be implemented in the entire region.

The sustainability of Padarlya model watershed program after the project phase will be ensured by the four key factors viz., effective participation of large members of community people (clearly indicating that they got tangible economic benefits and the watershed interventions met their needs), presence of strong and effective community-based organizations, availability of watershed development fund (for repair and maintenance of the structures during the post-project phase), and strong linkage with the village gram panchayats. At the start of the watershed program, there were only two members in the watershed committee from the gram panchayat, which gradually increased to five. Recently, in the watershed program, the village gram panchayat has achieved a lot of stake. During the watershed program, Capacity Building Organizations (CBOs) were given high priority to make them effective and strong. This will be further strengthened through capacity building, financial support, and by providing strong linkage with various institutions like market, banks, etc. These factors will go long way in sustaining the impact of watershed program behind the project phase.

Name of the project: Padarlya-Siyalwada watershed, Raisen, Madhya Pradesh

Key partners: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Bhopal Yuwa Paryavaran Shikshan and Samajik (BYPASS) Sansthan, Madhya Pradesh
Department of agriculture, Raisen
Department of animal husbandry, Raisen
Rajmata Vijayaraje Scindia Krishi Vishwa vidyalaya, Indore

Project duration: 2010 to 2015

Compiled by: P Pathak and Suhas P Wani (ICRISAT)

3.4 Enhancing livelihood through participatory watershed development under 'Himmothan Pariyojana'

The key problem:

The 'Himmothan Pariyojana' Social Awareness through Human Involvement (SATHI) implemented participatory watershed development activities in Amta Village, situated in Ghinni-Ghad region of Pachhad development Block of District Sirmour, Himachal Pradesh (HP). Most of the households inhabiting the village belong to the scheduled caste. Agriculture and animal husbandry were the major occupation undertaken by the villagers. The community was able to meet their food requirement from cultivation in their field. However, due to the increase in the population, deforestation, and erratic rainfall, crop production decreased which further resulted in to deterioration of the socio-economic status of the community. The people were purchasing fodder from far flung plain areas that proved to be costlier. Further, the erratic rainfall and lack of irrigation facilities resulted in low agricultural productivity. During the years 2000-2004, a continuous decrease was marked in the crop production, and the villagers were forced to grow only one crop. To compensate for the loss, people started the use of chemical fertilizers and pesticides. Initially, the village community was getting better yield from the use of chemical fertilizers but its continuous use resulted in hardening of soil and reduction in the soil fertility. The prevailing conditions led to economic constraints for the villagers as they had no other source of income. Besides the economic problem, the community was also facing severe scarcity of drinking water.

The solution:

In the year 2005, SATHI initiated to address the core area of concern in Amta village with the support of Sir Ratan Tata Trust under 'Himmothan Pariyojana'. After perceiving the prevailing situation, village level meetings were organized in which the local community was asked to discuss the core concern of the area among them. The community discussed the problems and suggested the probable solutions. SATHI with support of the local community identified 6.5 hectares of barren land to carry out the plantation work. To restrict the entry of animals in the proposed plantation patches and avoid the open grazing, local community has carried out social fencing work. Locally available spiky bushes were also used for the purpose. After the fencing work in the selected area, the construction of staggered trenches was initiated with an objective to reduce the flow of surface water and its percolation, which in turn will be helpful in recharging the groundwater level. As many as 489 staggered trenches have been constructed covering 4 ha of barren land (Figure 1).

Subsequent to the construction of staggered trenches in the plantation area, the local community extended the plantation work in 6.5 ha of barren land. For the same, local species of fuel wood and fodder plants were used to sort out the unavailability of fuel-wood and fodder. In addition, Napier grass saplings plantation was carried out on the raised bunds on the staggered trenches. The major objective of the same was to reduce the runoff of soil and increase the availability of grass in the plantation patches. Apart from the vegetative measures, engineering measures such as: construction of Brush wood check dams, Johris (Community ponds), loose bolder check dams (LBCDs), gabion structures, and earthen dam were executed. The major objective of the same was to reduce water flow during heavy rain, control soil loss and erosion, harvest rain water, and maintain moisture in the plantation areas. The drinking water well, irrigation tank, and ferro cement tanks were constructed to resolve the irrigation and drinking water crisis. To reduce the dependency of the villagers on the chemical fertilizers and motivate them to adopt organic ways of farming, vermicompost pits were constructed for all the households (Figure 1).

The impact:

Prior to the project intervention, the community was facing severe scarcity of water both for drinking as well as irrigation purposes. The project made significant effort to solve the above stated problem and constructed various structures for the same. Most of the agricultural land is covered with irrigation facility which resulted in incredible increase in yield of vegetables and other crops. Presently, the village community is growing seasonal and off-seasonal vegetables such as tomatoes, red chilies, peas, capsicum, green coriander, radish, turnip, etc., and getting better yields. Through plantation and other vegetative measures, there has been considerable increase in the availability of fuel-wood and fodder (Table 1). After the project interventions and community efforts, the barren land patches are now covered with dense forest. In the recent times, the villagers do not purchase grass from the plain areas instead they are selling grass to the adjoining villages. Following the catchment area treatment works, significant improvement in discharge of down-stream water bodies is evident and has become a perennial source of water. Further, the project intervention in the village has also led to considerable enhancement in the economic status of the community. The majority of villagers are now able to sustain their livelihood more efficiently and effectively. With the increase in income level, it is quite obvious to witness rise in their living standards.

Table 1. Details of grass production from the plantation area (year 2010-2014).

Sr No	Year	No. of Pullas (local units)	Estimated cost (₹)
1	2010	12340	37,020
2	2011	16000	56,000
3	2012	21800	76,300
4	2013	26085	91,175
5	2014	28950	101,325
Total		105175	361,820

Integration or Inclusiveness:

To ensure community participation in the project activities, the village level meetings were organized among the local community. The villagers were informed in detail about the activities of the project and encouraged to ensure their active participation in project planning, implementation, monitoring, and evaluation. To ensure community participation, the project formed watershed development committee (WDC), along with the User Group (UG) and women self-help group (SHG) to empower the local women and make them self-reliant. These groups carry out savings, microcredit functions, loan operation, and income generating activities. The local community, members of WDC, SHG and UG actively participated in the site selection, execution of physical works, monitoring of physical activities, and benefit sharing mechanism, etc.

Lessons learnt from this approach:

Implementation of participatory watershed development activities under 'Himmothan Pariyojana' was a unique learning experience for SATHI as well as the beneficiary community members. After the execution of the project, it was learnt that the community mobilization and involvement is very essential for the effective and efficient implementation of any program meant for socio-economic development of the rural communities. The organization also learnt that while dealing with the NRM issues, technologies adopted should be simple, cost-effective, sustainable, and environmental friendly. The local community now realizes the importance of biodiversity conservation and is much more aware about the judicious use of natural resources, i.e., water, land, forest, etc.

The way forward:

After the project implementation, sustainability of the various vegetative and engineering measures was a major challenge. Thus, the project has formed UGs in which all the beneficiaries are members to ensure the operation and maintenance of water harvesting structures. The key responsibility of the UGs is to ensure equal sharing of water and grass (fuel-wood-fodder) among the beneficiaries. The project has ensured 50% women participation in SHG formation. The group elected its president and secretary for a definite time period. The group members also collect some fixed amount, ie, Rs 10/- or Rs 20/- as O & M contribution on a monthly basis, and president/secretary deposits this amount in the group bank account. This amount may be used in any O &M /developmental activities in the near future. Moreover, the SHG formed in the village is also functioning effectively. The SHG group conducts regular meetings and performs saving and inter-loaning operations. The village has emerged as a role model for the watershed development and participatory NRM interventions.

Name of the project: Enhancing livelihood through participatory watershed development under 'Himmothan Pariyojana'

Key partners: Sir Ratan Tata Trust (SRTT), Mumbai (Funding Agency), SATHI, Thakurdwara, Sirmour (HP), Himmotthan Society, and PSI, Dehradun.

Project duration: Jan 2006 to Dec 2008

Compiled by: Biswanath Sinha, Sir Dorabji Tata Trust (SDTT)

3.5 Enhancing Livelihood Resilience of the Tribal Communities in Khedbrahma block, Sabarkantha district, Gujarat

The key problem:

The project area is situated in the Northern part of Sabarkantha district in Khedbrahma taluka, Gujarat. The project villages falls under Poshina tribal belt in the catchments area of Sabarmati river, situated 50 km away from Taluka head quarter, and about 110 km from Himmatnagar district. The socio-economic conditions of the people are marginal to poor with rainfed agriculture as the major source of livelihood along with animal husbandry. Migration is also a common phenomenon in these regions especially during the lean seasons. With the degradation of the natural resources, lack of community organization and access to information and extension services, the livelihoods of the communities has been under high stress. Agriculture is very much at its rudimentary level. The major crops that are grown in the area are mostly the food crops (Maize), pulses (Pigeon pea and Black gram), and cotton with irrigation facilities. The banking sector has still not reached the village, and hence, the credit flow to the farmers comes mostly from the traders cum money lenders. These traders are also suppliers of ration and other essential commodities with very high interest on capital advanced to the farmers for various purposes.

The solution:

The watershed approach to the treatment of the land resources was a very critical investment as the land, though degraded, was the only asset available with the communities. The interventions aimed at improving the land resources through a range of soil and moisture conservation interventions. The optimum and judicious utilization of the available land resources, development and management of the created additional irrigation sources, promotion of efficient use of water, improvement in the agricultural practices, and mobilization of the communities were the critical sub-components that were converged with the Tata Trust support into these cluster villages. The project covered 1025 households in six tribal villages. The activities being implemented under the project are mainly focused on the (i) formation of farmers' institutions and user groups relating to the agricultural production, (ii) soil and water conservation efforts in line with watershed treatment work, and (iii) capacity building of farmers around good agricultural practices. The project was implemented by VIKSAT.

The impact:

Various demonstrations and trainings were organized for capacity building of the tribal farmers. The strategy of performing the demonstration was carried out in three different modes, i.e., core, extension, and campaign that have benefited the farmers for cultivation of food crops. The trainings with continuous follow up have developed knowledge among the farmers based on improved practices. The rudimentary sets of practices around agriculture have been significantly replaced through training related interventions. The farmers have been practicing and following the same practices for increasing the agricultural productivity leading to a stabilized livelihood. During the extension work, composite variety of seeds for maize was promoted. The promotion and use of improved variety of seeds have resulted in more than 60% yield. During the project, strong linkages were also established with institutions like state agricultural universities and Krishi Vigyan Kendras, etc.

There has been a notable increase in the land use pattern as a result of SWC work. The increase in the water availability for agriculture has resulted in the increase of area under cultivation during the *kharif*, *rabi*, and summer seasons. One of the fallout is that the farmers feel secure to invest in agriculture in today's time than they were before the intervention. The cropping intensity has increased significantly from 174% to 188% (Figure 1).

The undertaken soil moisture conservation work has led to farmers' motivation for the cultivation of cotton seeds, pigeonpea, and second crops like wheat. Overall, the soil moisture conservation has contributed to increase in productivity by 25%. The soil health has also increased with the implementation

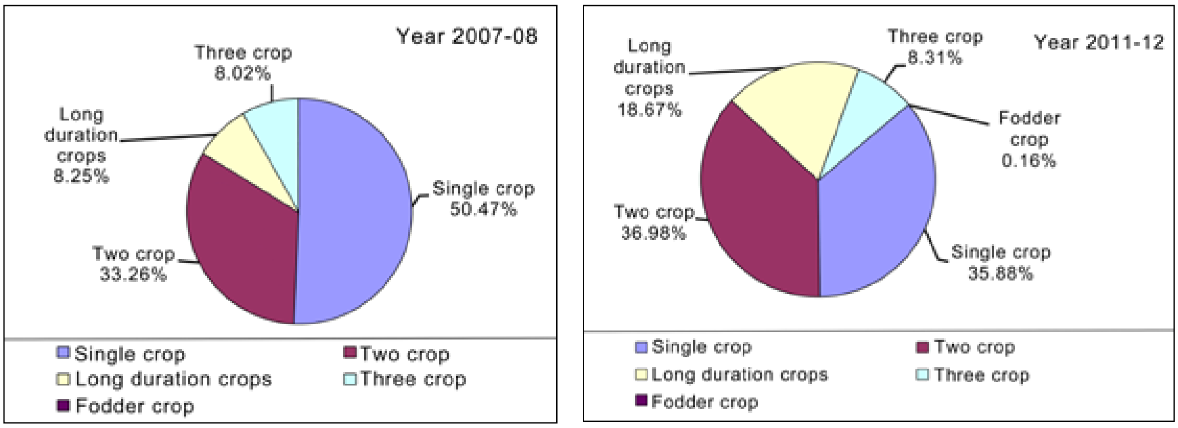


Figure 1. Land use change during and after the watershed management interventions.

Figure 2. Water harvesting structure along with chili crop in the watershed area.

of soil moisture conservation work that has helped in arrest of soil erosion. The total gross income derived from the land was ₹ 5725 per hectare, which has increased by six folds to ₹ 34495 per hectare; however, the increase of income may be considered as the combined efforts for the promotion of SMC work and appropriate extension inputs for agriculture.

The area under irrigation has increased from 25% to almost 75%. The same land that would have remained fallow during the *rabi* season, now grows crops, and hence, the area under agriculture has increased for those who have been benefitted under the activities that included well deepening and strengthening, group irrigation, etc. The data reveals that at least four new crops are being grown; three being oilseeds and one pulses. The area under crops during the *rabi* season has increased as water can now be used to irrigate using the infrastructure that was provided. The income has also increased at current price by 114% whereas that at constant price income has increased by 86%. Similarly, the drip irrigation systems promoted under the program are mostly used for growing vegetables, and the farmers have benefitted in terms of additional income.

Lessons learnt from this approach:

- Gradual and consistent capacity building by increasing the participation of people in village development activities is critical for long-term sustainability of the same. Exposure visits, video shows, and awareness programs are more effective ways of information dissemination.

- Imparting knowledge about agricultural package of practices through demonstrations and organizing field days have proved to be very effective tools for wider dissemination of improved agricultural practices. Participation in farmer training, on-site hand holding support by the field staff, and sharing of experiences have led to increased acceptance of the emerging agricultural practices.
- Availability of assured irrigation facility is an important pre-requisite for sustainable development in the agriculture sector.
- With assured irrigation facilities, land development, and increased awareness, farmers are shifting toward growing more cash crops like cotton and cotton seed plots. This has led to increased income levels, and reduction in area under subsistence food cropping like maize and pigeon pea.

The way forward:

Each household will be supported for at least three years. It will be in the form of enhancing their knowledge and capacities, creating and providing irrigation infrastructure, establishment of strong community institutions with clear roles and responsibilities, diversified livelihood options, and prototypes such as agriculture and livestock based on the risk minimization and optimal return. It is envisaged that these focused inputs will help to increase the household income to ₹ 1.2 lakh from the current baseline of R₹ 35000. This increased income will enhance the investment capacities. The irreversibility will be taken care through building knowledge base, enhancing capacities, community-led extension systems, and strong community institution interface. The specific inputs for capacity building will be provided to the members as well as institutions. The forward and backward linkages with markets and other financial institutions will be established that will increase the access to various inputs, including credit. Further linkages will be established with the village level PRI to help strengthen the governance structure as well as leverage of the government program. The high value agricultural produce (vegetables and fruits) will be produced in context of the local market. Also, nursery entrepreneurship will be promoted at the village/ cluster level for quality seedling. The local level value addition such as grading and sorting will be taken care locally. The backward and forward linkages will be established between SHG/VO/Federation and local market facilitators/commission agent.

Compiled by: Biswanath Sinha, Sir Dorabji Tata Trust (SDTT)

3.6 Integrated Watershed Management Program: BAIF's Experience in Telangana State

The Key Problems:

After successful implementation of DPAP and APRLP watershed Projects, BAIF undertook the implementation of Mukarlabad, Manthatti, and Bhootpur watershed projects in the Telangana state. The key problems of the area are:

Low Productivity, Mono-cropping: The farmers are cultivating rainfed crops and adopting mono-cropping preferably by growing crops like red gram and paddy. Low productivity was observed in case of rice (17.10 q/ha) and red gram (3.5 q/ha) cultivation against the average productivity for rice (26.68 q/ha) and red gram (5.63q/ha).

Depleting Groundwater Table: The average rainfall in the area was recorded as 749 mm per annum. The distribution and intensity of rainfall was uneven with long dry spells in the rainy season. In general, the groundwater table goes down to 200 feet in the summer season, 165 feet in winter, and about 132 feet in the rainy season. Due to the lowering of water tables, the farmers are not interested in creating irrigation sources by investing a huge amount. There is shortage of drinking water for human and animals during summer and winters.

Non-Availability of Potable Water: High TDS (950 PPM) and fluoride (2.0PPM) content in drinking water causes harmful effects on the human health such as early bone and teeth decaying, discoloration and shriveled skin.

Major population having Marginal and Small Holdings: Most of the farmers in the project area have small and marginal holdings that range between 2 to 2.5 acres. In addition, 9% of the cultivable land was undulating with boulders, harder for cultivation, and possessed low productivity.

Low Potential Milch Animals: Approximately, 4250 non-descript animals were valued at ₹ 4500 to 5000 per animal, yielded 1 to 1.5 lit milk/ day, which was very low as compared to the upgraded animals yielding average of 15 to 18 liters of milk/day.

Migration: Small holdings with low productivity and no dairy development with non-descript animals, the population from the project area migrated outside in search of other livelihood sources.

Solutions: Keeping in view, identification of the problems in a participatory way and considering the topography of the area, an intensive and integrated approach towards the management of natural resources was developed. The key components of program are given below:

- Establishment of a three door step Artificial Insemination (AI) center for upgradation of local livestock for higher productivity and creating valuable assets with families was considered to be an innovative way for the Entry Point Activity (EPA). These centers render AI services to 28 villages. Another EPA was providing safe drinking water to the community through establishment of 04 RO plants in the fluoride affected and high TDS areas.
- The natural resource conservation measures include soil and moisture conservation measures like 600 LBS, 5 MPT, 6 check walls and 100 gully checks, and 12 gabion structures. The series of 75 check dams were constructed for harvesting of the runoff water and groundwater recharging.
- The crop productivity improvement has been achieved through improved seed varieties, vegetable cultivation, and floriculture. The dryland horticulture plantation has been undertaken on 475 ha with mango orchards. The new valuable vegetable crops like carrot, cabbage, tomato, and chili have been included in crop diversification.
- The project established three custom hiring centers and facilitated individuals to procure the agriculture implements from Agriculture, Horticulture Department, and others under productivity system improvement.

The impact: Apart from the conservation of soil and more moisture for crops, Table 1 gives some direct results:

There was an increase of about 40% of the area under irrigation across all the watershed sites. Increase in the groundwater table has been observed to the extent of average 133 feet due to the enhanced recharge. Due to the created and assured source of irrigation, the barren land of 85 acres was brought under cultivation. The following impacts were observed after the post-project analysis.

- **Valuable assets-** Due to increased productivity of the land, the value of land has increased by 50% (5-6 lakh/acre) over the pre project land value.
- **Reduced migration-** Migration has reduced by 30% as the beneficiaries have started working on their farms. This has reduced the dependency on external wages.
- **Enhanced milk productivity and increased population of other ruminants-** Three AI centers under the project are rendering door step AI services for high pedigree semen produced 435 calves of high potential breeds. The milk productivity also increased by 15% due to breed up-gradation program. Also, the population of other ruminants like sheep and goats has increased by 41% and 32%, respectively, as area exposed under the variable vegetation provided grazing facility for the ruminants.
- **Crop diversification and cultivation mechanization–**Farmers have started cultivating crops in two seasons. They have included vegetable crops in crop diversification and have enhanced the productivity by 25% and farm profitability by 20%. Also, the farmers have converted 475 ha of 625 ha cultivated area under mango plantation. Three custom hiring centers have been established under Entry Point Activity (EPA) that are responsible for providing mechanized farm implements like cultivators, weeders, rotavators, and sprayers on rent basis to the farmers. It has helped to minimize the capital cost and dependency on agricultural laborers. Six drying yards having capacity to dry 8 tons of grains/day was facilitated to maintain the purity of the grains.

Table 1. Outcomes of the Watershed Project.

Sl.No	Particulars	Pre project analysis	Post project analysis
1	Groundwater table	200 feet during summer 165 feet during winter 132 feet during rainy season Average-165 feet	170 feet during summer 123feet in winter 107 feet during rainy season Average-133 feet
2.	Soil Moisture Index	Poor	Improved
3	Irrigated area	1277 ha	1787 ha
4	Barren land brought under cultivation	Nil	85 acres

Drinking water- High TDS (950 ppm) and fluoride (2.0 ppm) content in drinking water of the project villages caused various health ailments. By considering the need, four reverse osmosis units were installed for providing safe drinking water to 2000 villagers. Four cattle troughs have been constructed to provide drinking water for the cattle and small ruminants.

Solar street light- 36 solar street lights have been erected in six watershed villages to overcome electricity shortage.

Integrated and inclusive approach:

IWMP is linked with NREGA for wage payment, issuing of job cards, and mobilization of laborers to work in the site. IWMP project designed with 5000 ha area for each project covering 5 to 6 micro watershed villages, per ha unit cost of ₹ 12000 covering the material cost. The wage component of the project is covered under NREGA program. Cumulatively, ₹ 10 crore was spent for different IWMP interventions by splitting ₹ 9.1 crore as the material cost covered under IWMP program, and ₹ 90 lakh as wage payments to be distributed to the wage seekers covered under the NREGA program. The drought prone areas exhibit climatic variables and unequal rainfall distribution that imposes restricted cropping pattern for the area. By adopting NRM works for water harvesting and soil and moisture conservations techniques, intensive cropping systems have been introduced to integrate the watershed program. The rain water harvesting structures could provide irrigation facilities for agriculture by direct lifting and recharging of the groundwater that enabled farmers to lift water from their irrigation sources. Also, the groundwater table recharged from 165 feet to 133 feet, and the area under irrigation increased from 1277 ha to 1787 ha.

The productivity system improvement provided seeds of high yielding varieties, promoted vegetable cultivation, and floriculture created crop diversification in the area. The fodder development in crop diversification encouraged the farmers to rear milch animals as additional source of income. Due to the increased water availability, the farmers are able to diversify their crops and grow two crops per

Table 2. Crop diversification shifted from mono to mixed, multiple and intensive cropping systems in the project area.

	Cropping Pattern	
Sl. No	Pre project	Post project
	Mono cropping	Mixed cropping/Intensive cropping
1	Red gram	Redgram+ Jowar Red gram + Cotton Jowar + Castor
2	Paddy	Vegetables, Ground nut, and Floriculture
3	Black and Green gram	Jowar+ Green gram/Black gram

season in some of the project areas. The watershed has also enhanced the water-use efficiency through the introduction of drip and furrow irrigation. Also, 80 households adopted drip irrigation out of 158 households and benefited from the mango plantations. The cultivation of high value-vegetable crops such as carrot, cabbage, tomato, and chili, as well as flowers, is possible only due to the increase in water availability.

Lessons learnt from this approach:

- Community participation is the key factor in the success of watershed management approach. The watershed committee actively participated in all the processes of implementation and also insisted the farmers for judicious use of the stored water.
- Electronic fund management system was introduced on the lines of NREGA for transparency and timely release of the funds. This system generates wage payment on volumetric accuracy and directly deposits the wages to the bank accounts of the wage seekers.
- AI centers established under the program is rendering AI services at doorstep of the farmers with marginal charges resulting in enhanced milk production in the area leading to second major source of livelihood.
- Custom Hiring Centre (CHCs) and Productivity System Improvement activities helped bring the crop diversification.

The livelihood diversification has been created in the project area by increasing cross breed cows and upgraded buffaloes under EPA activity by running three AI centers. The population of small ruminant also increased in the project area due to variable vegetation cover. It helped in improving the economic status of the farmers. The Productivity System Improvement activity motivated the farmers for cultivation of high value vegetables and floriculture products. It increased their per capita agricultural income. The soil and moisture activity implemented under the project, enhanced the productivity of the agriculture crops by minimizing soil erosion.

The way forward:

Plans for up-scaling:

- Organizing exposure visits of farmers/other agencies to the site from different areas to create awareness on the impact of check dams on crop and livelihood diversification.
- Documentation and publication on impact/utility of the approach.
- Trainings to the farmers, watershed extension workers, NGOs, and technical experts and scientists, on the integrated watershed management program.

Figure 1. Water harvesting structure and drying yard in the watershed.

Sustainability:

The Village Watershed Development Committees (VWDC) are formed and strengthened by conducting trainings on the structure management and judicious use of water. VWDC will charge nominal fee for lifting of the stored water from the structures, and the collected corpus can be utilized for maintenance of the structure.

Project partners-District Water Management Agency, VWDC, NREGA, Community, and BAIF

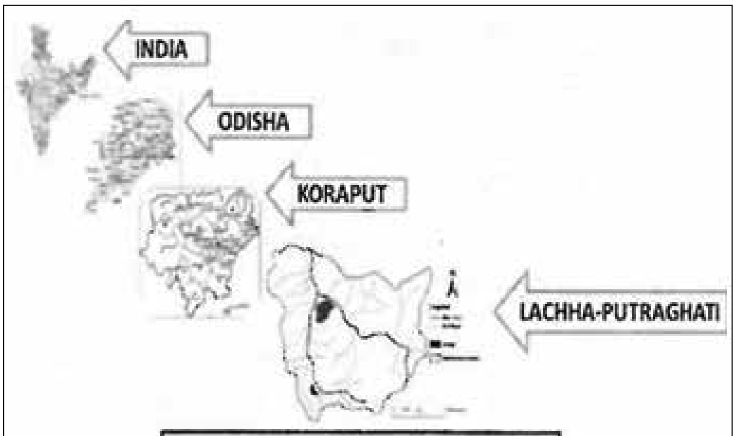
Project Duration- 7 years

Compiled by: Girish Sohani, BAIF Development Research Foundation

3.7 Tribal Participation for Watershed Management in Eastern Region of India

The Eastern region of India constitutes about 63% of the net sown area under *rainfed agriculture* and supports a population of 290.8 million (Madhu et al. 2014). The region has a predominance of tribal (54 tribal communities) constituting about 17.3% of the total population. About 62.5% of the total geographical area of Eastern region is degraded exclusively by the water induced soil erosion which in conjunction with salt-affected and acidic soils, works out to be 73.9%. The indiscriminate deforestation and practice of *Jhum* cultivation lead to accelerated erosion for which proper conservation measures need to be established especially on the very steep slopes. A model watershed in the tribal dominated areas of Odisha was implemented by ICAR-IISWC, Research Center, Sunabeda, Koraput under the MMA, NWDPRA, sponsored by the MoA, GOI, New Delhi. Koraput district (110) is one among the top one-third districts (167) based on the high *Rainfed* Areas Prioritization Index (RAPI) by the NRAA (2012). The tribal population of the district is 46.6% and 84% of the total population that is below poverty line (BPL). The overall aim of this case study is to assess the impact of watershed development activities on community participation, productivity efficiency, economic and environmental efficiency, and relevance of watershed implementation policy guidelines in the tribal-dominated micro watershed in the Eastern region of India.

Location Lachhaputraghati (LPG) watershed is located in Pottangitehsil of Koraput district in Odisha state. The watershed is 20 km away from Semiliguda town and 45 km away from Koraput district headquarter. The geographical location is 82°56' to 82°58' E longitude and 19°45'30" to 19°47'30" N latitude with an elevation range of 900 m to 1258 m above the mean sea level (msl). The total area of the watershed is about 601.24 ha with undulating steeply sloping (up to 50%) topography. 0f 601.24 ha of the total geographical area, maximum area is under degraded forest (61%) followed by the net cultivated area (20.15%), current fallow (11.5%), area under non-agricultural use (6.0%), and under pasture land (1.4%). The average land holding is 0.52 ha and an average family income is ₹ 2500 per month.



Location Map of Lachha-Putraghati Watershed (Code No.III-05-04-02-02)

Resource conservation and livelihood activities for watershed development: Various interventions were undertaken for the watershed development based on the problems, needs, priorities of the watershed community, their technical suitability, and economic viability. The watershed development activities undertaken in the watershed development program are soil and water conservation measures in the arable lands, water resource development, productivity enhancement activities, entry point and income generation activities, and community organization including capacity building. The activities under resource conservations are vegetative filter strips, field bunding, hedge planting, stone bunding, and trenching. The live check dams, brushwood check dams, loose boulders check dams, gabion structures, and stream bank stabilization are the implemented measures for the stabilization of gullies and drainage networks in the watershed. The water resources in the watershed area were developed through farm ponds, jhola candies, renovation of water harvesting structures, and providing water conveying systems. To improve the productivity of lands measures like Agri-horticulture systems, bamboo plantation, fuel and fodder plantation, silvi-pasture system, and agronomic management practices were taken up in the watershed area.

Productivity impact indicators: The different productivity impact indicators are assessed before and after the watershed interventions and are presented in Table 3.

Resource use efficiency impact indicators: The different resource use efficiency impact indicators are assessed before and after the watershed interventions and are presented in Table 4.

Environmental impact indicators: The different environmental impact indicators are assessed before and after the watershed interventions and are presented in Table 5.

Socioeconomic impact indicators: The different socio-economic impact indicators are assessed before and after the watershed interventions and are presented in Table 6.

Technical man days at different phase of watershed: The technical man days at watershed work phase worked out to 2.3 and 3.0 man day ha-1(71% of the total man days) in total and the treatable area in the watershed, respectively (Figure 6). The technical man days accounts for only 12 and 17% of the total man days ha^{-1} during the preparatory and consolidation phase of the watershed, respectively. The technical man days were slightly higher during the consolidation phase due to the completion of pending works coupled with data collection and analysis for impact evaluation.

Table 3. Productivity impact indicators in the tribal participated LPG watershed intervention.

Biophysical Impact Indicators				
Indicators	Unit	Before (2008)	After (2012-13)	Change (%)
Productivity Indicators				
i. Productivity of crops	%	9.14		
ii. Crop diversification index		0.55	0.71	30
iii. Cultivated land utilization index		0.35	0.4	14.3
iv Crop productivity index		0.55	0.61	12
v. Crop fertilization index		0.21	0.3	43
vi. Watershed productivity (Ragi Equivalent Yield -REY)	kg ha^{-1}	4,962	6,126	19
vii. Av survival rate of mango	%	68		
viii. Human Population Carrying Capacity				
Av. Energy output	Mj ha^{-1}	18,296	20,006	9.30
Av HPCC of land	Adult ha^{-1}	4	4.4	9.30
Jholaland	Adult ha^{-1}	6.6	7.2	8.50
Beda land	Adult ha^{-1}	4.2	4.6	9.70
Padda&Denger land	Adult ha^{-1}	2.7	3	8.50

Table 4. Resource use efficiency impact indicators in the tribal participated LPG watershed intervention.

Biophysical Impact Indicators			
Indicators	Before (2008)	After (2012-13)	Change (%)
II. Resource use efficiency indicators			
i. RWUE (kg ha^{-1} mm^{-1})			
Av. Cereals	2.14	2.35	9.9
Av. Pulses	1.47	1.63	11.2
Av. Food crops	1.95	2.15	10.2
Av. Oil Seeds	1.04	1.11	6.9
Av. Vegetables	28.92	31.55	9.1
Av. Spices	23.44	25.71	9.7
Average for all crops	11.89	12.99	9.3
ii. EERW (MJ m^{-3})			
Av. Cereals	4.35	4.78	9.8
Av. Pulses	3.26	3.63	11.2
Av. Food crops	4.04	4.45	10.1
Av. Oil Seeds	2.49	2.67	6.9
Av. Vegetables	7.15	7.78	8.7
Av. Spices	4.17	4.57	9.7
Average for all crops	4.71	5.12	8.7

Table 5. Environmental impact indicators in the tribal participated LPG watershed intervention.

II. Biophysical Impact Indicators					
SI.No	Indicators	Unit	Before (2008)	After (2012-13)	Change (%)
III. Environmental impact indicators					
1 Potential Soil Erosion Rate					
i	Arable	t ha^{-1} yr^{-1}	17.93	15.61	12.90
ii	Non-Arable	t ha^{-1} yr^{-1}	37.23	30.38	18.40
iii	WS Average	t ha^{-1} yr^{-1}	30.24	25.03	17.20
iv	Soil retention capacity of trenches	t ha^{-1}	13.69		
2	Estimated Runoff	%	14.68 to 29.92	7.3 to 15.4	
i	Av.runoff	%	24.4	14.6	40
3	Development of Water Resources				
i	Created storage capacity	ha-cm	93.91		
ii	Additional area under irrigation	ha	24.2		
iii	Av.water table depth	m	2.97	2.8	5.90
iv	Av.depth of water in well	m	0.99	1.17	17.80
4	Density of trees	trees ha^{-1}	7	14	7
5	Induced watershed eco-index		0.04		4
6	Carbon Sequestration Potential	Years	10	20	
i	C	t ha^{-1} yr^{-1}	2.12	3.40	-
ii	C Credit	₹ ha^{-1} yr^{-1}	2544	4080	-

Table 6. Socioeconomic impact indicators in the tribal participated LPG watershed interventions.

IV. Socioeconomic Impact Indicators					
SI.No	Indicators	Unit	Before (2008)	After (2012-13)	Change
1	Overall People's Participation Index	**%**	56		
2	Av. Family Income	(₹ yr^{1})			
i	Large		35,700	41,000	5,300
ii	Medium		21,854	31,700	9,846
iii	Small		13,750	18,770	5,020
3	Av. Family Expenditure	(₹ yr^{1})			
i	Large		28,500	34,000	5,500
ii	Medium		18,600	27,500	8,900
iii	Small		13,500	18,300	4,800
4	Employment Generation	Man Days	14,052		
5	IGAs (Annual income per SHG)	₹	14,000	40,000	
6	Amount in WDF Account	₹		121,252	
7	The Economic Viability of the Project				
i	BCR at 10% DR		1.16		
ii	IRR (%)		19.S		

Policy recommendations:

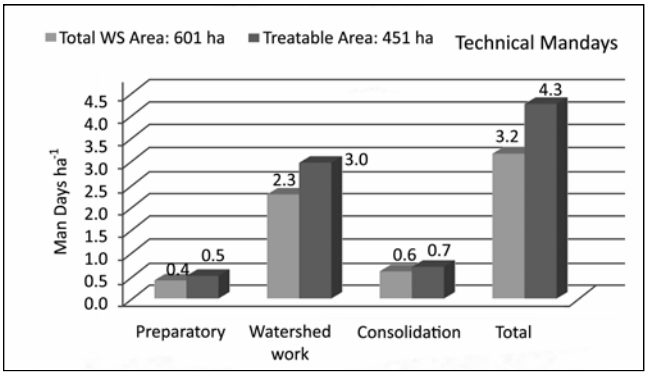


Figure 6. Technical man days at different phases of watershed development.

Working with the tribal community needs a lot of persuasion and commitments. The watershed level institutions like watershed committee, SHGs, and UGs performed well during the project implementation with active community participation. The SHGs initiated under the watershed program also built awareness and confidence among the women groups, but their active continuation needs linkages and marketing support. This may be possible through formation of the federation at district level and linking all the SHGs under this federation for their effective performance. Contributions towards works, particularly from SC/ST are somewhat difficult since many development program works with 100% support from the program/scheme which contradicts the contributions under the program. A suitable strategic approach is required for the effective utilization of fund under WDF account even though it is meant for post project maintenance of assets created under the program. The effectiveness of land treatments, water resource development, and overall NRM management is diluted due to other components in the program that requires more concentrated *efforts* without much focused outcome or impacts. Particularly, the plantation work suffe*rs a* lot due to the competition with agricultural activities during the monsoon period. The earth work component of the plantation may be taken up before or after the monsoon period or during lean agricultural activity so that planting can be done with the onset of monsoon to increase the yield and generate employment. In the tribal areas, all the plantation areas should be supported with vegetative fencing to protect and prevent uncontrolled grazing.

Compiled by: PK Mishra, Central Soil & Water Conservation Research & Training Institute (CSWCRTI)

4. Irrigation Management

4.1 Water Impact Calculator: A simple and farmer-friendly decision support system for irrigation scheduling

Agriculture is the largest consumer of freshwater and utilizes nearly 70% of the total amount of water in crop lands. Inappropriate management of water resources results in low crop yields and poor water use efficiency (WUE). The conservation and efficient use of water resources both at micro and meso scale (farmers' field and watershed scale) is essential for enhancing crop yield, productivity, and income. For efficient utilization of the water resources, there is an urgent need to enhance WUE through enabling the farmers to adopt need-based irrigation scheduling and efficient irrigation methods.

The involvement of farmers in general practice calendar-based irrigation scheduling resulted in over irrigation and poor WUE. Due to the inherent variability of bio-physical (soil hydraulic parameters, soil depth, etc), topographical, and land management (cropping sequence, time of sowing, etc) factors, calendar-based irrigation scheduling does not always match with crop water requirement resulting in reduced crop yield and poor WUE. Therefore, it is required to follow the need specific water application to optimize the available water resources use. A decision support system called as "Water Impact Calculator" (WIC) is developed using the strategic data collected at ICRISAT research station along with the supporting literature through a desktop study. While developing WIC, it is primarily considered that the tool should be simple and user-friendly in terms of data requirement. The user should quickly enter the input data relating to their farm, develop a quick understanding of the important water-related impacts, and get irrigation scheduling. Microsoft Excel is found as a suitable computational platform for developing WIC.

ICRISAT-led consortium with local partners (NGOs), and irrigation company (Jain Irrigation Ltd.) started farmers' participatory field trials during the years 2010-2014 in different model watersheds and pilot sites (e.g., MotaVadala in Jamnagar, Gujarat; Kothapally in Ranga Reddy, Telangana, India; Parasai-Sindh watershed, Jhansi; Dharola Tonk, Rajasthan; and ICRISAT research station) (Figure 1). Based on the minimum WIC inputs on soil type, soil depth, date of sowing, and climatic data, the exact amount of water on suitable dates were recommended in drip and flood/furrow irrigated fields. The gravimetric soil moisture content was measured from 0-15, 15-30, 30-45, and 45-60 cm of soil depths at weekly interval. The crop grain yield and above ground biomass yield were estimated at the end of the crop harvest and compared with the traditionally managed fields.

The farmers at pilot sites could save nearly 30% of water due to the need-based irrigation application. For example, soils at Jamnagar site are shallow and characterized by poor water holding capacity. Frequent irrigation (once in a week) is generally followed in these areas resulting into 10-14 irrigation for growing wheat and 8-10 irrigations for chickpea crop (Table 1). As per WIC calculation, irrigation frequency and

Figure 1. WIC field demonstration on irrigation scheduling in groundnut crop using drip and sprinkler irrigation system.

amount of water use was reduced to 30-40% compared to the traditionally managed fields. The actual water requirement of wheat crop under drip irrigation system was estimated to be 460 mm. Moreover, the farmers using furrow methods were recommended to irrigate net 520 mm water against 950 mm in control plots (farmers practice) in the year 2011-12. This saved 430 mm irrigation water (45% less) compared to the control fields. Similarly, irrigation requirement for chickpea was estimated at 300 mm under the drip irrigation system. The farmers using furrow methods were recommended to apply 420 mm water against 580 mm in control fields in the year 2011-12 (Table 1). This has resulted in 160 mm water saving against the calendar-based water application. Similar to Jamnagar, the farmers in Tonk followed the recommended irrigation practices and resulted in 100-150 mm water saving compared to the traditionally managed fields as shown in Table 1. The results showed that excess irrigation in traditionally managed control fields resulted in substantial amount of deep percolation compared to WIC-managed fields (Table 1). The deep percolation from drip irrigated system was almost negligible. The losses due to deep percolation in case of WIC-managed fields were reduced by 50-80% compared to the calendar-based irrigation.

Table 1. Irrigation water requirements, actual irrigation applied, crop yields in farmers' participatory experimental trials at Mota Vadala (Jamnagar), Dharola (Tonk), and Kothapally (Ranga Reddy) during the year 2011-12.

	Water applied by farmers in WIC-trial fields (Actual)	Water applied by farmers in WIC- trial fields (Actual)	Water applied by farmers in traditionally managed control field (calendar based) (Actual)
Method of Irrigation	Drip	Flood	Flood
MotaVadala, Gujarat			
Crop grown	Wheat	Wheat	Wheat
Irrigation water (mm)	460	520	950
No of Irrigation (-)	7	6	13
Crop Yield (t ha^{-1})	6.3	5.8	5.9
Deep Percolation (mm)	80	150	540
Crop grown	Chickpea	Chickpea	Chickpea
Irrigation water (mm)	300	420	580
No of Irrigations (-)	5	6	9
Crop Yield (t ha^{-1})	2.2	1.8	1.8
Deep Percolation (mm)	50	150	310
Dharola, Tonk, Rajasthan			
Crop grown	Wheat	Wheat	Wheat
Irrigation water (mm)	260	300	410
No of Irrigation (-)	5	4	5
Crop Yield (t ha^{-1})	3.5	3.4	3.5
Deep Percolation (mm)	10	30	90
Kothapally, Telangana			
Crop grown	Tomato	Tomato	Tomato
Irrigation water (mm)	400	590	700
No of Irrigation (-)	9	8	10
Crop Yield (t ha^{-1})	8.7	8.3	8.3
Deep Percolation (mm)	20	150	220

In addition, despite applying 30-40% less water, the yields obtained from WIC-managed fields were comparable with the control practice (Table 1). For example, the measured wheat yield from WIC-recommended plot was 5.8 t ha^{-1} compared to 5.9 t ha^{-1} from calendar-based irrigation plot in the year 2011-12 at Jamnagar. The wheat yield was further found to be higher (6.3 t ha^{-1}) under drip irrigation plot that was guided by WIC. Similar results were recorded in different years at various testing sites.

Way forward:

The excel-based farmer-friendly water impact calculator (WIC) is a simple tool to use and requires simple data that a user can easily provide. The WIC potentially could be a decisions making tool for small-scale field applications, and the farmers can take decision on cropping system and irrigation applications. The WIC enables farmer specific support considering every parameter (soil depth, texture, moisture retention) of the farmer's field, and different land management practices (sowing date and crops) for identifying specific water-based solutions. The WIC enabled to save at least 30-40% water in irrigated area that currently channeled through non-productive evaporation and other losses and led to poor water use efficiency. Moreover, 30% saving in irrigation water would directly reduce the cost of pumping or energy requirements and could save a minimum of Rs 1000-1500 per season per ha.

The existing simulation tools such as CROPWAT are robust but their uses are limited to the scientific community due to the complex parameterization. WIC, on the other hand, is simple in use, requires very elementary details and computes water balance as per the logical framework. There is no separate installation needed for WIC as it is developed in Microsoft Excel. We targeted important and primary stakeholders like line department officials (eg, Department of Agriculture, Department of Horticulture, Watershed Department, Command area development authority, Land and water resources, etc., at state and national level in India and elsewhere), NGOs, and other implementing agencies to use WIC for site-specific water management and irrigation scheduling.

Compiled by: Kaushal K Garg and Suhas P Wani (ICRISAT)

4.2 Micro irrigation for enhancing water use efficiency

The problem:

Jalgaon is one of the water scarce districts in Maharashtra having major area under rainfed conditions. The important crops of this district are cereals followed by cotton. Fruit crop production (especially banana) that has been extensively cultivated using surface (flood) method of irrigation in the district resulted in poor water use efficiency. The limited availability of fresh water and its poor management has led to decline in the crop yield. Hence, there is an urgent need to enhance the irrigation efficiency by adopting advance method of irrigation like micro-irrigation techniques.

Innovation:

The cotton farmers belonging to the Jalgaon region designed an innovative cotton plant spacing scheme in drip irrigation while keeping the plant population same as recommended. The recommended plant spacing for cotton is 90 x 60 cm that requires 111 laterals per hectare. Instead, the farmers practiced a plant spacing of 180 x 30 cm that requires only 55 laterals per hectare. The changed plant spacing led to reduction in the cost per lateral by about 50%. It also resulted in better aeration between the two rows. As the spacing is wider, the crops like green gram, black gram, soybean, etc., can easily be intercropped with cotton. This gives additional income to the farmers, as well as improves soil fertility. This type of drip irrigation structure is also cost effective and gives a better crop yield (17 to 18% more) against the traditional practices. More than 400 farmers (corresponding to about 260 hectares) have successfully adopted this practice. It has also reduced the labor requirements to one third.

Drip irrigation in sugarcane and cotton.

Integration or inclusiveness:

This was the first initiative by Government of Maharashtra (GoM) with the support of central government along with different partner organizations who are dealing with water scarcity issues, water productivity, and yield improvement in agricultural and horticultural crops, involvement of private companies (Jain irrigation systems Ltd, NETAFILM,etc), National horticulture Mission (NHM), Water and Land management Institute (WALMI), National Committee on Plasticulture Applications in Horticulture (NCPAH), State Micro Irrigation Committee (SMIC), and District Micro Irrigation Committee (DMIC). Jain irrigation systems Ltd brought together the partners along with Government of Maharashtra (GoAP), MV Foundation.

Lessons learnt from this approach:

The micro-irrigation approach helped in taking progressive steps towards saving water, increase productivity, health of soil, maintain groundwater level, ensure sustainability, and positive impact on food security. The modified drip system, by managing the lateral spacing, has been used for agricultural crops like cotton that was cost effective and helped provide a 15% increase in the yield.

The way forward:

The farmers in these regions have shown the potential to overcome the water scarcity problems and bridge the large yield gaps by actively adopting the water saving technology of drip irrigation systems. However, these efforts need to be supported by enabling policies of government that will help them to adapt technology in the changing climatic conditions with reference to the present situation. The extension services supported the farmers by capacity building/awareness raising exercise and training, as well as by facilitating the development of a local private-sector supply value chain including post-sales services for the drip systems and services. The advanced technologies with traditional knowledge need to be carefully integrated to increase and restore resilience along with better access to the markets through collective cooperation.

Compiled by: Sachin Malve and Suhas P Wani (ICRISAT)

ICRISAT-India (Headquarters)
Patancheru, Telangana, India
icrisat@cgiar.org

ICRISAT-India Liaison Office
New Delhi, India

ICRISAT-Mali (Regional hub WCA)
Bamako, Mali
icrisat-w-mali@cgiar.org

ICRISAT-Niger
Niamey, Niger
icrisatsc@cgiar.org

ICRISAT-Nigeria
Kano, Nigeria
icrisat-kano@cgiar.org

ICRISAT-Kenya (Regional hub ESA)
Nairobi, Kenya
icrisat-nairobi@cgiar.org

ICRISAT-Ethiopia
Addis Ababa, Ethiopia
icrisat-addis@cgiar.org

ICRISAT-Malawi
Lilongwe, Malawi
icrisat-malawi@cgiar.org

ICRISAT-Mozambique
Maputo, Mozambique
icrisatmoz@panintra.com

ICRISAT-Zimbabwe
Bulawayo, Zimbabwe
icrisatzw@cgiar.org

ICRISAT appreciates the support of CGIAR investors to help overcome poverty, malnutrition and environmental degradation in the harshest dryland regions of the world. See http://www.icrisat.org/icrisat-donors.htm for full list of donors.

132-2016