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Final report

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2 Executive summary

More than half of India is undergoing serious water stress. The accelerating and alarming rate of groundwater depletion continues unabated. In rural communities, groundwater decline constrains food production, jeopardises farm incomes, catalyses increased urban migration and fractures community cohesion and harmony. Groundwater scarcity also means rural women and girls are spending more time carrying water, more energy use and higher cost of pumping, increase in groundwater salinity and degradation of surface streams and dependent aquatic ecosystems. The project LWR/2010/015, Managing Aquifer Recharge and Sustaining Groundwater Use through Village-level Intervention (MARVI), used a participatory and transdisciplinary approach at village level to engage farmers and other community members to monitor groundwater, rainfall and check dam water levels and use this information along with agronomic, social, economic and cultural aspects to develop capacity of villagers for sustainable groundwater management.

The project employed methodology to engage and train villagers, called Bhujal Jankaars (BJs), a Hindi word meaning 'groundwater informed'. BJs are local volunteers who were involved in developing village level science for community engagement and participatory groundwater management. With appropriate training and capacity building, BJs successfully monitored groundwater levels, rainfall, checkdam water levels and water quality, making sense from a village perspective of what is happening to village groundwater recharge and availability. BJs conveyed this information to farmers and others in their own language and help in the planning and the use of groundwater at the local level. BJs are an effective, trusted and valuable interface between village communities and government agencies, NGOs and researchers. They helped to create village scale rich data sets through their monitoring of rainfall, watertable depths in dug wells and tube wells, groundwater quality in wells and water level fluctuations in selected check dams. Through the analysis of data collected by BJs and on-going engagement of village communities and stakeholders, the project initiated a dialogue with the Central and State Governments and created pathways for adoption of project outputs in the Government of India's 'National Groundwater Management and Improvement Program' project being developed for implementation in seven states of India.

A water balance model was developed and applied to the Dharta watershed to estimate recharge from four check dams monitored over a two-year period. A simple daily water balance was carried out for four check dams in the Dharta watershed where farmers took daily measurements of check dam water levels and rainfall for 2 years. The farmer's measurements were proven to be highly reliable. The study revealed that the check dams augmented recharge by 33 mm in 2014, an ''average'' year, and by 17 mm in 2015, a ''dry'' year (where recharge is expressed as depth over the combined catchment area of the check dams). This corresponded to 2.0 and 1.0 times the combined capacity of these check dams in those years, and the average annual recharge volume, 743,000 m^3 which can support16% of agricultural production in the rabi (winter) season from the surrounding villages. Total recharge was estimated to be 37% and 70% of combined runoff in 2014 and 2015, respectively. Mean dry weather infiltration rates averaged from the four sites over both years were 5–8 times the evaporation rate from check dams. Hence, based on farmer measurements, the study indicates that check dams are effective and efficient in recharging the local aquifer. The water balance methodology developed in the project is simple and with some training it can be used by farmers to determine the changes in infiltration trends in check dams and thus the need for desilting of check dams in the following dry season and to provide essential data for quantification of recharge from check dams. Further the methodology developed is cost-effective and reliable and effectively engages farmers and therefore it can be implemented widely to monitor more check dams and other water balance parameters. As such, the monitoring and water balance analysis provides local quantitative data that can inform on sizing and placement of check dams in relation to local benefits, capital and maintenance costs and downstream impacts, and thereby inform future investment opportunities in check dams at district and state levels.

The socio-economic analysis of the study areas indicated that there are four discrete and diverse groups or clusters characterised by different combinations of responses to the groundwater attitude questions. The four clusters were differentiated by whether irrigators are future oriented or more focussed on the present, how optimistic they were of positive future solutions, the role of managed aquifer recharge in sustaining the groundwater use and whether compensation should be forthcoming if wells are affected by the actions of other well owners (both positive and negative). Importantly, the distribution of the four clusters was different across the two watersheds. The results question the effectiveness of a uniform approach to assist communities to craft rules and strategies to reduce over-extraction of groundwater at the village level. Individual attitudes about aquifer connectivity, willingness to amend well operations, water conservation and time orientations vary across villages and watersheds. Importantly understanding the structure and distribution of attitudinal diversity means government programs to improve the groundwater situation should be tailored to match village attitudes thereby assisting communities to craft their own actions and institutions to improve groundwater sustainability and reduce the risk of program failure. Incomes, assets and farm size are also significantly different across the four attitudinal clusters, factors that may influence the willingness and capacity of individuals to engage in groundwater negotiations at the village level.

As to the role of groundwater in wellbeing of communities, the study indicated that water and soil quality in the Dharta watershed and income, land security and health services in the Meghraj watershed are the factors that will gain the highest levels of improved wellbeing. Implementing uniform wellbeing policies that fail to address these differences is likely to achieve inferior wellbeing improvement. An important finding was that there was a very low (less than 0.2) correlation between actual household income and farmer's level of dissatisfaction with income: both low and high income individuals were dissatisfied with their income. The policy implication is that a single reliance on improving household income through improved groundwater management does not equate to improved wellbeing in the watersheds, although this is less so in Dharta. If improved wellbeing is the primary or sole objective, government programs could be designed to align with a relatively consistent set of wellbeing factors across all villages located in each watershed. However, if sustainable groundwater and improved wellbeing are joint objectives, programs may need to be developed at the village level, not the whole watershed, to account for the diversity of observed attitudes to sustainability and wellbeing priorities.

During the project, a total of eight community forums, six local workshops and two national workshops were organised as part of the engagement and dissemination strategy. There was significant media coverage at the local, state and national levels through newspapers and television. The key messages covered were that participatory groundwater monitoring can successfully converge the expectations of farmers and scientists and can provide a sound basis for participatory management in the semi-arid hard rock areas of India. Managed aquifer recharge, which is already valued by farmers, requires government intervention and the BJ program could be used to assist in the development of localised groundwater management within the context of a whole of watershed or basin plan.

The National Workshop titled 'Groundwater Monitoring, Planning, Recharge and Sustainable Use: Village Level Participatory Approaches and Tools' during May 30-31, 2017 in Ahmedabad, India was effective in engaging key stakeholders and disseminating project findings. The workshop was attended by over 120 policy makers, researchers, planners, government officials, NGOs, private sector specialists, farmers and community groups. It helped to facilitate an active, vigorous and open dialogue to discover ways to strengthen the institutional capacity and frameworks for effective village-scale groundwater management. The workshop also helped to share lessons from the MARVI project and provided hands-on experience / demonstration of field tested MARVI tools, including MyWell app, and methodologies to effectively implement MAR works, assist communities craft both cooperative strategies and village level demand management.

One of the significant outcomes of the project is the formation of pilot ‘Village Groundwater Co-operative’ (VGCs) in the two study watersheds. A series of village level meetings were held during the last ten months of the project to identify issues and challenges related to the sharing of groundwater among farmers. Based on these discussions, key principles for operationalising VGCs emerged and were agreed to by the interested groups of farmers. As a result, three VGCs in the Dharta watershed and two in the Meghraj watershed have been formed and they are being formally registered. Overall, the project has been successful in developing an engagement model using the BJs and translated data and experience into farmer friendly groundwater knowledge and tools to help change the practices of farmers and save water while improving livelihood opportunities in the two states of India and beyond.

3 Background

India is the largest user of groundwater in the world with an estimated usage of 230 km^3 per year. Globally, areas under groundwater irrigation are highest in India (39 million ha), followed by China (19 million ha) and the USA (17 million ha). At present 204 $km^3 y^{-1}$ of groundwater is pumped annually in India. Several reasons may be attributed to this phenomenon. Access to groundwater has increased since the 1970s, when diesel and electric pumps became affordable to small land holders. The causes of increased groundwater use are also rooted in population growth and economic expansion, and as a result the annual groundwater use now exceeds the annual rainfall recharge. The notion of groundwater as a private resource, the rights of which are associated with land rights, has led to an exploitative extraction regime.

Farmers in semi-arid parts of India use groundwater to save rain fed crops from failure and to increase yields. As it is a relatively cheap and easily accessible water resource for individual farmers, irrespective of their farm size, groundwater is often extracted beyond its natural recharging capacity. With increased use of groundwater, the depth to watertable in many parts are fluctuating considerably during the year and the use of groundwater has risen to a level that groundwater from shallow aquifers is not adequate to meet the rising demand. Hence groundwater from deeper aquifers is being pumped by the drilling of tube wells. There are also instances where fresh groundwater at shallow depths has been depleted, rendering marginal quality water from deeper layers of the aquifer. The extensive use of groundwater resources by farmers all over the country pumping out water in an unregulated manner creates its own sets of complex management and sustainability issues.

In spite of all the efforts in the past to improve the sustainability of groundwater in India, the problem of groundwater management is still severe, particularly in Rajasthan and Gujarat. In this project, called *Managing Aquifer Recharge and Sustaining Groundwater Use through Village-level Intervention* (MARVI), the research is focussed on developing a suitable participatory approach and methodology with associated tools to improve supply and reduce the demand on groundwater. Another important aspect of the project is education of and engagement with village communities, local NGO and government agencies to facilitate them working together to achieve sustainable groundwater management.

Systemic analysis of the groundwater situation and livelihood opportunities from agricultural, environmental, social and economic perspectives was considered critical. Since groundwater is an invisible resource and difficult to regulate, the focus of any future intervention to achieve groundwater sustainability needs to be at village scale (micro catchment) and involve users directly. The aim is to analyse and understand the current situation and ground truth methods, as well as provide measures and tests to upscale strategies and extend benefits to watershed, regional and state levels. For this reason, the MARVI project focussed on collecting a range of hydrologic, agronomic, economic, social and cultural data at selected clusters of villages. Bio-physical and socio-economic data were used to evaluate the current issues of groundwater management, identify options and strategies that can improve the long-term access to groundwater, provide a scientific and evidenced-based input to enhance watershed development policies, and regenerate the natural resource base in irrigated farming systems.

4 Objectives

4.1 Overall Aim

The overall aim of this project was to improve the security of irrigation water supplies and enhance livelihood opportunities for rural communities. Specifically, the project had the focus on assessing the effectiveness of current rainwater harvesting and groundwater recharge structures and demand management strategies at village scale. The project also aimed to develop or adapt suitable best practice guidelines and modelling and assessment tools that can be applied with relatively easily available local information.

4.2 Specific Objectives

1. Identification and evaluation of the impacts of selected integrated programs that include MAR for sustainable irrigation water supplies, agricultural production and income generation in northern Gujarat and southern Rajasthan;
2. Evaluation and critical analysis of the effectiveness of village scale MAR and demand management interventions in selected study areas. Also, the development of alternatives that are acceptable to villagers for improving the security of water for agriculture and the income of farming families;
3. Development of community based approaches to local groundwater monitoring, recharge and demand management strategies;
4. Development/adaptation of suitable framework, tools and models for designing integrated MAR programs and assessing their impacts on local and regional water and food security; and
5. Development of best practice guidelines to assist in the selection of future MAR structures, demand management strategies and appropriate policy development in view of achieving the goals of NREGA and other similar investments.

As mentioned earlier, the focus of this project has been at the ‘village scale’ to ground truth methods and provide measures and tests to scale up to watershed and regional level. Overall, the study explored alternative strategic approaches for sustainable groundwater management in northern Gujarat and southern Rajasthan, two regions of India where groundwater over-development has emerged as a major issue, and where some approaches are already emerging for dealing with the problem.

4.3 Key Research Questions

The key research questions that were examined in relation to this project are:

- How effective is the planning, site selection, design and implementation of rainwater harvesting and groundwater recharge structures under NREGA and other watershed development programs at village scale in delivering equity and access to enhanced water supplies for agriculture?
- Are the current institutional, policy and social interventions effective for long term water security, food production and livelihood outcomes?
- What opportunities are there for village communities to improve water security and sustain farming through demand management strategies?
- Are there adequate linkages and convergence mechanisms among different watershed development activities to achieve local and regional water and food security goals?

5 Methodology

5.1.1 Overall approach

In terms of governance of this project, an overarching management committee met regularly (bi-annually) but informally via Skype or teleconference. This committee formed at the inception meeting and participants comprised of component leaders from within the project.

The study was focused in Gujarat and Rajasthan. There are some distinct similarities and differences in terms of MAR issues related to hydrogeological, socio-economic and agro-ecological conditions in Gujarat and Rajasthan. For example, groundwater supplies from hard rock areas play the major role in meeting irrigation demands in both states but the agronomic practices and socio-economic conditions in these states are different to some extent. The states provide diverse hydrologic and socio-economic conditions from the point of view of groundwater management for agricultural activities and food production.

Given the complex interactions of physical and socio-economic factors that affect recharge processes and the variability of these factors across the case study areas, it was important to have a clear understanding of the scientific and socio-economic impacts of the local water management problem (Mudrakartha, 2004). For this reason, the research in this project was conducted through impact assessment of two carefully selected study areas, one in northern Gujarat and the other one in southern Rajasthan, and supported by broader-scale assessments.

To enhance the impact of this project, it was considered important to increase awareness about groundwater dynamics and encourage village communities to observe and manage their water resources cooperatively. Such approaches have achieved success in Andhra Pradesh through the APFAMGS project (http://www.apfamgs.org/). For this reason, the project activities were designed for participatory hydrological data collection by researchers and farmers. In view of this, the development of a sound methodology for data collection and its implementation in the study areas was considered important. Working with carefully selected local partner NGOs greatly increased the data quality and knowledge base from the beginning.

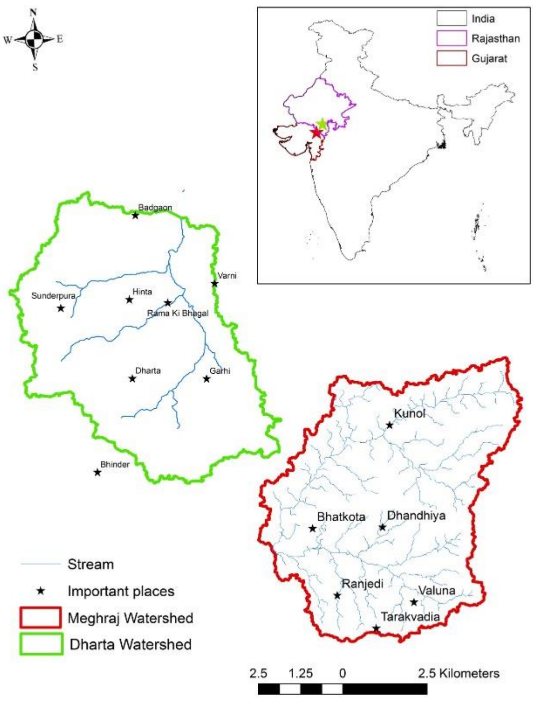

Figure 1. Location of the study watersheds.

This study was conducted in Aravali district in Gujarat and Udaipur district in Rajasthan (Figure 1). To ensure meaningful assessments of the MAR impacts, in each district the study area (cluster of villages – micro watershed) were selected such that it has some region (subset of cluster of villages) with significant level of investments in watershed development interventions (including MAR through NREGA) and some had much lower levels of investment. The key components of research methodology and the framework are shown Figures 2.

The novel aspect of this project is captured in the transdisciplinary research and the involvement of village communities to observe and manage their groundwater cooperatively. The conceptual underpinning in this project is the detailed analysis of economic, social and environmental dimensions of groundwater recharge strategies at local and watershed scale. The underlying approach adopted in the project was systemic, people-centred and holistic. Further, the approach used micro watershed based case studies (comprising one or more villages) to analyse and assess the current situation and identify strategies that can enhance economic, social and environmental outcomes of groundwater recharge enhancement activities. In particular, the approach involved the assessment of groundwater recharge structures and activities for their influence on watertable depth, water quality, local hydrology, sedimentation and agricultural activities. This was followed by both a financial and livelihood analysis with consideration given to issues related to each component of the water harvesting system for enhanced recharge (i.e. the catchment area, the recharge structure and the recovery area).

Overall, the approach outlined above helped us to understand and explore the full range of issues in groundwater management in northern Gujarat and southern Rajasthan. Specifically, we identified promising interventions (direct as well as indirect) that can contribute to sustainable groundwater management. The project also helped to synthesize lessons from the Indian as well as Australian experience on creating sustainable groundwater management regimes and assisting policy makers, NGO, state and central government agencies and other stakeholders associated with groundwater management.

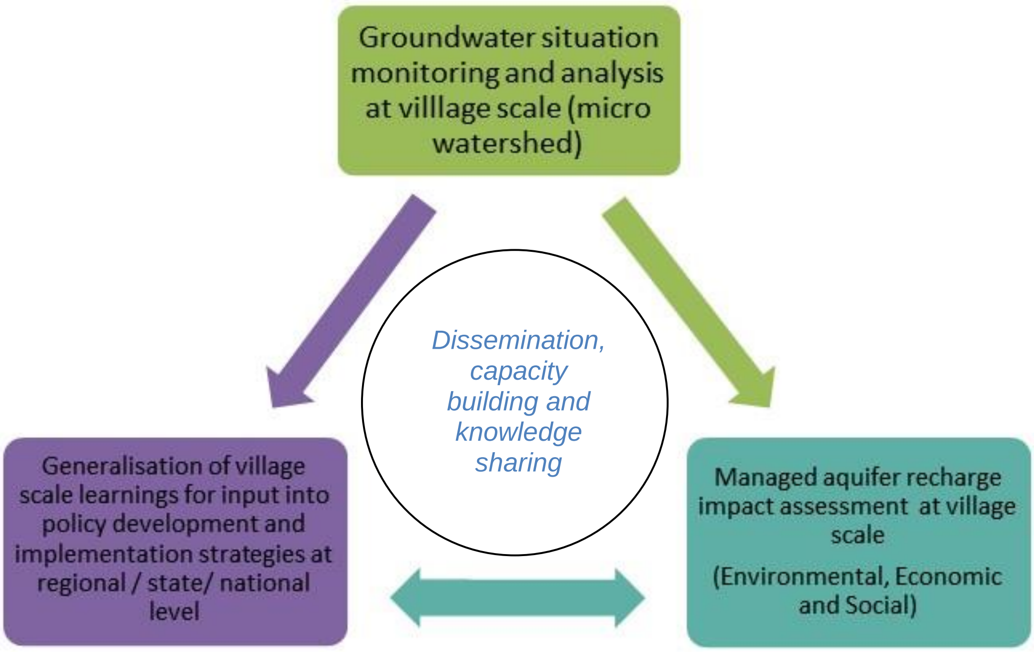

Figure 2. Key components of research methodology.

6 Achievements against activities and outputs/milestones

Objective 1: Identification and evaluation of the impacts of selected integrated programs that include MAR for sustainable water supplies, agricultural production and income generation in northern Gujarat and southern Rajasthan.

No.	Activity	Outputs/ milestones	Date of output/ milestone	Comment
0.0	Project establishment	• Agreement signed; • Relevant staff recruited in Australia and India; and • Project web page developed for: (a) secured sharing of documents and data among project partners and stakeholders, and (b) communication about the project to general public.	July 2011 December 2011	All three outputs/milestones have been completed. Now we also a separate project web site: www.marvi.rog.in .
1.1	Identify and review key WSD and MAR project sites, available data, project reports and other materials for selected sites and select integrated programs for MAR impact assessment.	• Meetings with government agencies, NGOs and other stakeholders conducted to gain an understanding of the nature and extent of past interventions and current and historic data and other information identified; • A document with critical review of available data, past project reports and other information from government departments and NGOs; • Integrated programs selected for MAR assessment; and • Prospective sites visited in Gujarat and Rajasthan for qualitative evaluation and ranked for more detailed assessment in 1.3.	October 2011 October 2011 December 2011	All four outputs/milestones have been completed. Also, a journal article was published from this review work: Prathapar, S., Dhar, S., Rao, G.T., and Maheshwari, B., 2015. Performance and impacts of managed aquifer recharge interventions for agricultural water security: A framework for evaluation. Agricultural Water Management, 159:165-175.

1.2	Conduct a workshop involving project partners and key stakeholders to develop a detailed framework for MAR impact assessment, a field monitoring program and stakeholders (including village communities) and project partner engagement strategy.	• Inception workshop held and common vision and ownership shared; • Key stakeholders for the project and their roles identified and Project Steering Committee established; • A detailed work plan and implementation strategy for the project documented (includes information and data collection framework for impact; strategy for regular communication among project partners and stakeholders documented, and agreed research opportunities and risks implementation plans); and • Cluster of villages identified in the two study areas.	February 2012	A three-day workshop was organised in Udaipur to achieve the three outputs listed. This workshop also included project visioning exercise.
1.3	Evaluate impacts of past MAR activities on groundwater tables, groundwater balance and availability of irrigation water at study areas.	• Detailed survey of MAR structures done in terms of their age, storage capacity, and groundwater recharge performance; • Past data on groundwater levels from relevant government agencies and other groups obtained and analysed to understand the trends in groundwater table fluctuation and water balance in the area. • Qualitative data on impacts of MAR activities obtained from farmers and other relevant stakeholders; • Report developed with title 'The performance of the past MAR interventions in improving irrigation water supplies: Understanding the key factors and lessons learnt in Gujarat and Rajasthan';	June 2012 September 2012 November 2012 February 2013	All four outputs/milestones have been completed. Also, two journal articles were published from this evaluation: 1. Chinnasamy P., Maheshwari B., and Prathapar S., 2015, Understanding groundwater storage changes and recharge in Rajasthan, India through remote sensing, Water, 7:5547-5565. 2. Chinnasamy, P., Misra, G., Shah, T., Maheshwari, B. and Prathapar, S., 2015. Evaluating the effectiveness of water infrastructures for increasing groundwater recharge and agricultural production - A case study of Gujarat, India. Agricultural Water Management, 158:179-188.

1.4	Evaluate impacts of past MAR activities on farming activities and livelihood opportunities in study areas and lessons learnt from selected WSD and MAR sites.	• Socio-economic data associated with selected integrated WSD program collected and analysed’ • Cropping data for the study areas from relevant government agencies for up to past 10 years obtained and analysed; • Focus group meetings conducted with farmers and other relevant stakeholders to understand how and to what extent MAR interventions in the study area influenced farming and income generation opportunities; and • Report developed with title ‘Effectiveness of the past MAR interventions in Gujarat and Rajasthan in improving agriculture and livelihood opportunities’.	June 2012 September 2012 November 2012	All four tasks have been completed and data from these tasks were used in performance evaluation study. One of the key outputs of this component is the following journal article: Shah, T. and Maheshwari, B., 2017. Community Based Groundwater Recharge Movement in Gujarat, India: Understanding its Impacts on Groundwater Availability. Groundwater for Sustainable Development (under review).

PC = partner country, A = Australia

Objective 2: Evaluation and critical analysis of the effectiveness of village scale MAR (including maintenance activities) and demand management interventions in selected study areas. Also, the development of alternatives that are acceptable to villagers for improving the security of water for agriculture and income of farming families.

No.	Activity	Outputs/ milestones	Date of output/ milestone	Comment
2.1	Identify specific field sites for detailed study and characterise them.	• Consultation with local government agencies, NGOs and farmers completed and development of criteria for identifying specific field sites in the study area; • Key local supporters and collaborators (including schools and village councils) of the project identified and briefed about the project activities and their role in the study; • GIS map of the study areas developed and soil, crops, wells, MAR interventions and other related features identified on the map; • Available past climatic data (rainfall and temperature) for the study areas obtained and analysed to understand the broad climatic trend and availability of rainfall for groundwater recharge;	December 2011 June 2012 December 2012 December 2012	All tasks have been completed and a series of GIS maps have been produced.

2.2	Monitor weather, groundwater table and stream flow and other biophysical parameters and understand the groundwater dynamics and water quality effects through modelling and other analyses.	• Relevant instruments purchased, installed and staff trained; • Data monitored at six monthly intervals and posted on the project web page for use by the project team; • A conceptual water balance model adapted/developed and tested and rainfall, surface water and groundwater interactions examined and documented; • A suitable groundwater model adapted/developed and tested and the influence of specific MAR interactions examined and documented; and • Water quality changes in aquifers documented, particularly in relation to human health and irrigation-related parameters.	February 2012 June 2012 and on-going June 2013 October 2015 October 2015	A groundwater balance model has been developed and tested. A journal article is currently under review in Agricultural Water Management journal. Chinnasamy, P., Maheshwari, B., Dillon, P., Purohit, R., Dashora, Y., Soni, P. and Dashora, R., 2017. Estimation of Specific Yield Using Watertable Fluctuations and Cropped Area in a Hardrock Aquifer System of Rajasthan, India. Agricultural Water Management (under review). Also, water quality data have been collected and interpreted and a journal article is being prepared.

2.3	Design and execute socio-economic survey in the study areas and document socio-economic trends.	• Key data needs and methodology for data collection and sampling approach established; • Development and pretesting of surveys and other data collection methods done; • Baseline of socio-economic profile of the study areas and a report prepared; • Surveys at six monthly intervals of the farm families to understand the trends in cropping patterns, and availability of water, livelihood and other relevant aspects and reports prepared;	February 2012 June 2012 December 2012	A total of 800 farmers were interviewed in the two study areas. The following two key journal articles summarise the output of this evaluation: 1. Ward, J., Varua, M.E., Maheshwari, B., Oza, S., Purohit, R., Hakimuddin and Dave, S., 2016. Exploring the relationship between subjective wellbeing and groundwater attitudes and practices of farmers in Rural India. Journal of Hydrology, 540:1-16. 2. Varua, M.E., Ward, J., Maheshwari, B., Oza, S., Purohit, R., Hakimuddin and Chinnasamy, P., 2016. Assisting community management of groundwater: Irrigator attitudes in two watersheds in Rajasthan and Gujarat, India. Journal of Hydrology, 537:171-186.
2.4	Evaluate technical effectiveness of MAR for recharge	• Report on cost effectiveness of maintenance for MAR operations and groundwater replenishment and submit a journal paper based on this; and • Training conducted on maintenance of MAR with partner organisation and representatives from communities.	November 2016	Costs of constructing and maintaining MAR structures were obtained and the following journal article was published: Dashora Y., Dillon P., Maheshwari B., Soni P., Dashora R., Davande S., Purohit R. C. and Mittal H. K., 2017. A simple method using farmers' measurements applied to estimate check dam recharge in Rajasthan, India. Sustainable Water Resources Management, (in press), DOI: 10.1007/s40899-017-0185-5. Also, an article on cost-benefit analysis of MAR structure is being prepared.

2.5	Conduct workshop, interviews and focus group discussions involving government agencies, NGOs and researchers to examine the role of demand management strategies for securing irrigation water supplies.	• A synthesis report based on outputs from 2.1 to 2.4 and findings from the workshop prepared.	November 2016	Workshop was held at DSC during December 2015.

PC = partner country, A = Australia

Objective 3: Development of community based approaches to local groundwater monitoring, recharge and demand management strategies.

No.	Activity	Outputs/ milestones	Date of output/ milestone	Comment
3.1	Developing a sound understanding of issues, opportunities and constraints.	• A working paper summarising local issues, opportunities and constraints to community based approach.	November 2011	Completed.
3.2	Design and pilot community based groundwater monitoring and management program.	• A compilation of best practices for participatory community monitoring and management of groundwater; and • A preliminary report titled 'A new model of participatory watershed development with focus on groundwater management'.	March 2012	Completed. A report has been written and a journal article is under review. .
3.3	Identify and train five young men and five young women as *Bhujal Jankaar* (Groundwater Knowledge Broker) apprentices.	• Intensive training and capacity building of Bhujal Jaankar trainees in intuitive hydro-geology and groundwater monitoring and sampling and maintenance of MAR.	March 2012	Completed. BJ training manual and BJ Program establishment manual has been finalised for wider distribution.
3.4	Awareness enhancement and groundwater knowledge dissemination through local school community.	• A detailed work plan developed for School engagement for their involvement in groundwater monitoring.	March 2012	Five schools in the Dharta watershed and six in the Meghraj watershed were involved for the entire duration of the project.
3.5	Capacity building of local communities through organising 'Farmer Field Schools'.	• Process documentation and a water budget developed by local communities through participatory approach and Bhujal Jaankars' involvement.	November 2012 – June 2017	A number of forums and field days were organised at six monthly interval during the duration of the project.

3.6	Conduct a workshop involving community stakeholders and researchers to critically assess the pilot.	• Report titled 'Engaging and empowering local communities for groundwater monitoring, recharge and demand management strategies: Lessons learnt and a framework for implementation'.	February 2017	A workshop was organised in February 2017 at ACT Bhuj and an evaluation report has been produced. This report is being converted into a journal article.

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Objective 4: Development/adaptation of suitable framework, tools and models for designing integrated MAR programs and assessing their impacts on local and regional water and food security.

No.	Activity	Outputs/ milestones	Date of output/ milestone	Comment
4.1	Examine MAR lessons from Gujarat experience in the context of conditions and experiences in Rajasthan sites and ACIAR project in Eastern India.	• Discussion paper on Successes and Limitations of MAR for Augmenting Water Supplies.	November 2012	A discussion paper was developed and it is being converted into a journal article.
4.2	Develop/adapt a suitable methodology for assessing local and regional impacts of MAR on surface and groundwater water availability and sustainability.	• A draft report synthesising hydrologic, agronomic and socio-economic data and learning from objectives 2 and 3 for developing methodology for MAR impact assessment and the definition of sustainable groundwater use.	October 2016	A preliminary analysis regarding upscaling of MAR using WaterCress has been done. A paper related to cost-benefit analysis of MAR is currently under preparation under guidance of Dr Peter Dillon.
4.3	A workshop to define range of application of the methodology developed in 4.1, and how it could be modified for use over a wider geographic scope.	• A report with appropriate framework, tool(s) and model(s) (including the analysis of impact factors monitored) for MAR impact assessment.	November 2016	The following journal article has been published: Dashora Y., Dillon P., Maheshwari B., Soni P., Dashora R., Davande S., Purohit R. C. and Mittal H. K., 2017. A simple method using farmers' measurements applied to estimate check dam recharge in Rajasthan, India. Sustainable Water Resources Management, (in press), DOI: 10.1007/s40899-017-0185-5

PC = partner country, A = Australia

Objective 5: Development of best practice guidelines to assist in the selection of future MAR structures, demand management strategies and appropriate policy development in view of achieving the goals of NREGA and other similar investments.

No.	Activity	Outputs/ milestones	Date of output/ milestone	Comment
5.1	Identify and document key factors for the selection of suitable MAR structures and effective demand management strategies from experiences in Gujarat and Rajasthan (including identification of key agencies who will be interested in MAR and demand management strategies).	• A working document summarising the key experiences related to the selection of MAR structures and effective demand management strategies and their applicability to other regions (including Eastern India). • Agencies interested in MAR and/or demand management strategies have been identified.	November 2016	The following two reports/papers have been developed: 1. Coping with Seasonal Groundwater Scarcity in Hard Rock Aquifers of Western India: Farmers Practices and Perspectives of Key Strategies; 2. Improving Groundwater Water Productivity of Maize in Western India: The Role of Mulch, Improved Variety and Organic Manure
5.2	Develop best practice guidelines to assist in the selection of future MAR structures and demand management strategies.	• A document developed on best practice guidelines for the selection of MAR structures and demand management strategies.	November 2016	The work of Yogita Dashora's PhD plus the outputs from 5.1 are being developed into best practice guidelines for groundwater management strategies.
5.3	Conduct a workshop with government agencies (including NREGA), NGOs and local stakeholders to identify the steps for incorporating learning from the project into policy and implementation of MAR works and demand management strategies in Gujarat, Rajasthan and other parts of India.	• Workshop conducted and key outcomes documented.	February 2017	A national workshop was conducted in May 30-31, 2017 and was attended by about 120 people from different parts of India. This was an important milestone of the project in terms of bringing different elements of the project together and engaging with key stakeholders and policy makers nationally. Also, this event attracted significant media interest in India.
5.4	Develop integrated report summarising key outputs and learning outcomes from the project	• Report on MAR-focused Participatory Watershed Management and Groundwater Monitoring	June 2017	This output relates to this report. Also, we developing a report that will integrate the various elements of the project outputs for wider dissemination within and outside India. One of the outlet being pursued is one of the GRIPP (IWMI) case studies.

PC = partner country, A = Australia

7 Key results and discussion

7.1 Estimating check dam recharge

India has made extensive use of groundwater for irrigation in hard rock areas that occupy 65% of the Indian land-mass. In many areas groundwater levels have fallen because natural supply of groundwater cannot keep up with demand. Therefore, in the absence of effective local groundwater demand management, government, non-government organisations and farmers since the 1960s have established check dams in ephemeral streams along with other watershed management improvements to augment groundwater recharge and help sustain supplies.

Check dams, sometimes called anicuts, are simply weir structures in river beds and follow traditional practices to detain runoff during the monsoon allowing greatly increased time for infiltration into the stream bed. Percolation tanks are similar but involve an earthen embankment and a spillway to perform the same function. Since the 1960s more than 75,000 check dams and percolation tanks have been built in Gujarat (CGWB 2013) and there are estimated to be well in excess of 200,000 in hard rock areas of India, mainly in Rajasthan, Maharashtra, Haryana and Tamil Naidu.

While many farmers and organisations attest to the effectiveness of these recharge structures less than 30 have been quantitatively evaluated and results have been variable. There are simple methods to measure infiltration rates and these require measurements of water level in the check dam frequently, such as daily. For researchers to visit check dams daily is very time-consuming and water level measurement probes are expensive and have proved unreliable in practice.

7.1.1 The MARVI Solution

An obvious solution is for local farmers to undertake these measurements. In the MARVI project this became part of the training and functions of farmers who were selected as BJs (Bhujal Jankaars). They also measured rainfall daily and water levels in nearby dug wells weekly.

In the MARVI project four check dams were monitored in the Dharta catchment, Rajasthan for three years and four check dams were monitored in Meghraj catchment, Gujarat, for one year (Figures 3 and 4). The Meghraj catchment is in the Aravalli Hills where land was more undulating and streams were steeper and narrower so check dams were smaller and more closely spaced than in the gentler terrain of Dharta.

A survey with a dumpy level was performed at each check dam to be monitored when it was dry to determine the area and volume of water that would be contained when water was any given level on a gaugeboard painted on a wing wall of the check dam. This survey would normally be done by engineers involved in check dam design and construction.

Figure 3. Hinta check dam in wet and dry conditions in Dharta catchment, Udaipur District, Rajasthan.

Figure 4. The Badgaon check dam water level measuring gauge with water level exceeding check dam crest level.

The farmers' daily data throughout the wet season until the check dam had dried were collected weekly and put into a spreadsheet to calculate recharge rate and volume and evaporation, and on wet days the amount of inflow and any spill. This water balance gives an accurate volume of each component in dry weather, and an estimate of each component in wet weather (Table 1). Several check dams were desilted allowing the impact of desilting to be assessed.

Table 1. Estimation of water balance components of check dams: (a) 2014 and (b) 2015.

	Recharge structure	Rainfall (mm)	Total inflow (m^3)	Total recharge (m^3)	Total spill (m^3)	Total evaporation (m^3)	Total recharge/total inflow (%)	Total recharge/capacity	Emptied
(a)									
1	Badgaon	505	349,000	113,000	218,000	19,000	32	2.86	Oct 14
2	Dharta	535	1,312,000	299,000	954,000	64,000	23	2.19	Dec 14
3	Hinta	771	949,000	518,000	358,000	91,000	55	2.32	Jan 15
4	Sunderpura	485	54,000	46,000	0	8,000	85	0.71	Oct 14
	Total		2,664,000	976,000	1,530,000	182,000	37	2.02	
(b)									
1	Badgaon[a]	614	189,000	56,000	129,000	4700	27	1.34	Aug 15
2	Dharta[a]	596	192,000	157,000	0	44,000	81	1.12	Nov 15
3	Hinta	673	331,000	286,000	0	63,000	86	1.28	Nov 15
4	Sunderpura	406	13,000	11,000	0	1600	88	0.17	Aug 15
	Total		725,000	510,000	129,000	113,300	70	1.00	

[a] Badgaon and Dharta check dams were scraped in 2015 before the monsoon

7.1.2 Key findings

- Farmers are highly effective in taking measurements to quantify recharge and schedule check dams for desilting. Their accuracy was verified by photographs of water level gauges.

- The study revealed that the check dams augmented recharge by 33 mm in 2014, an ‘‘average’’ year, and by 17 mm in 2015, a ‘‘dry’’ year (where recharge is expressed as depth over the combined catchment area of the check dams). This corresponded to 2.0 and 1.0 times the combined capacity of these check dams in those years, and the average annual recharge volume, 743,000 m^3, supports 16% of agricultural production in the rabi (winter) season from the surrounding villages. Total recharge was estimated to be 37% and 70% of combined runoff in 2014 and 2015, respectively. Mean dry weather infiltration rates averaged from the four sites over both years were 5–8 times the evaporation rate from check dams. Hence, based on farmer measurements, it is conclusive that the studied check dams are effective and efficient in recharging the local aquifer.
- The study demonstrated that a simple method can be used by farmers with basic training to determine the need for desilting of check dams in the following dry season and to provide essential data to allow quantification of recharge from check dams. This opens the possibility of scaling up by orders of magnitude the number of check dams evaluated. With more check dams monitored over longer periods, quantitative data would become available to inform on sizing and placement of check dams in relation to local benefits, capital and maintenance costs and downstream impacts, and thereby to inform future investment in check dams.
- Preliminary analysis of desilting suggests that it is effective in increasing recharge especially if done by hand labour that avoids river bed soil compaction by heavy machinery.
- With the advent of the “*My Well*” phone app farmers’ check dam data could be uploaded easily to a shared data base and the same algorithms used to automate calculation of water balance components, and to determine the priority for desilting the check dam in the coming dry season. It would then be possible to apply this method to thousands of check dams across India to evaluate performance, provide guidance for local action to improve water management and to help inform further investment in stream bed recharge structures. With more check dams monitored over longer periods, information would become available to improve sizing and placement of check dams in relation to local benefits, capital and maintenance costs and downstream impacts.

7.2 Coping with Temporal Groundwater Scarcity

Groundwater levels in hard rock aquifers in western and southern India fluctuate drastically during a year, in response to monsoon rainfall recharge, low specific yields of aquifers and pumping. A steady decline in groundwater levels occurs due to a series of pumping sessions during post-monsoon months. If the groundwater level drops below the bottom of a dug well, the owner of the well will experience temporal groundwater scarcity, until the onset of next monsoon (Figure 5). Temporal groundwater scarcity in areas with no access to canal water or limited rainfall demands unique coping strategies from farmers.

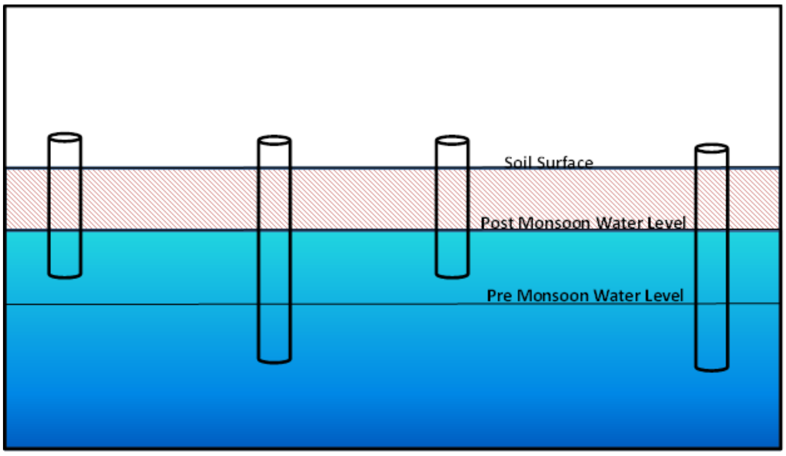

Figure 5. Schematic representation of temporal groundwater scarcity

7.2.1 Possible options for farmers to cope with temporal groundwater scarcity?

Coping with temporal groundwater scarcity will require strategies to maximize storage and minimise consumption of groundwater. Groundwater supply management strategies mainly focus on managed aquifer recharge; whereby natural runoff is detained to increase opportunity time for infiltration. The availability of groundwater, both regarding quality and volume, needs to be considered for developing coping strategies for the future.

Strategies to minimise demand for groundwater require an understanding of what happens to pumped water. A part of pumped groundwater is consumed beneficially (crop transpiration) or non-beneficially (soil evaporation). Non-consumed fraction of pumped groundwater is recoverable fraction if it recharges freshwater aquifers, and non-recoverable if it recharges saline aquifers. When managing groundwater demand, it is essential that water transpired by a crop is met, and if possible, its entire crop-transpiration demand is managed to maximise production. Therefore, demand management strategies to cope with temporal groundwater scarcity should primarily focus on reducing non-beneficial consumption and a non-recoverable fraction. Secondary consideration should include the costs of recycling and the quality of recoverable fraction.

7.2.2 How are farmers coping with temporal groundwater scarcity in India?

Understanding farmers' practices and perspectives are vital to devise policies and incentives to manage temporal groundwater scarcity because it is at the farmer level that most water is consumed. Therefore, a survey was conducted in five villages in Dharta Watershed, Udaipur district, Rajasthan and three villages of Meghraj Watershed, Aravalli district, Gujarat. Although these villages belonged to two different states, they are only 150 km apart, and agro-ecologically they are similar. In both watersheds, groundwater in hard rock aquifers is the main source of irrigation water; the rainfall is mostly monsoonal with about 75-90% occurring between June and September; the topography is undulating, therefore unsuitable for canal irrigation. The main objective of the survey was to identify farmers' practices and perspectives of on-farm water management strategies to cope with temporal groundwater scarcity. The survey was administered to 99 farmers (75 in Rajasthan and 24 in Gujarat) in February 2013.

7.2.3 Key findings

- Water scarcity was perceived as the most severe factor limiting agricultural production by 72% of the farmers, the second most limiting factor at 13% of the farmers, and the third most limiting factor by 7% of the farmers. Drying up of dug wells, however, appears very common (Figure 6).

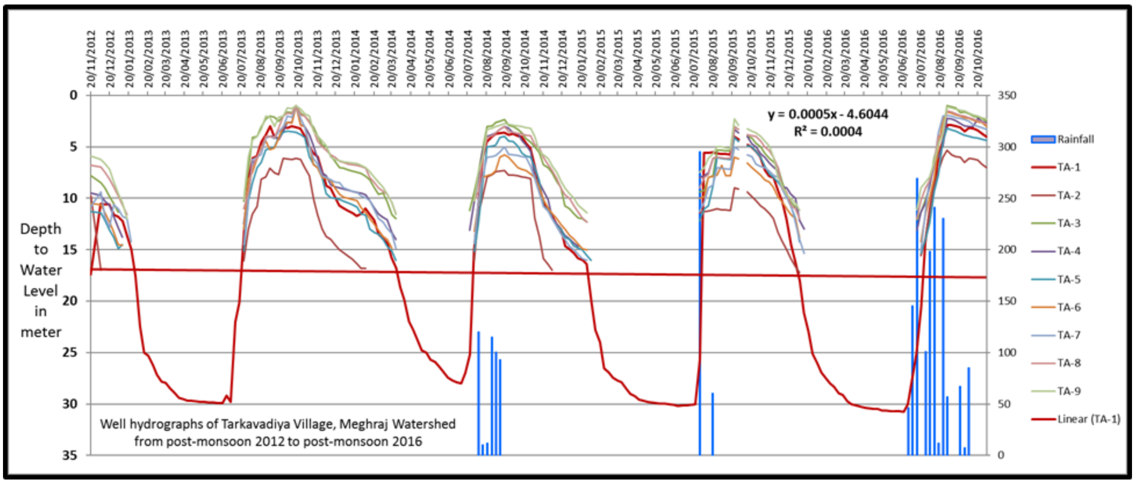

Figure 6. Watertable fluctuation due to rainfall events in selected wells in the Meghraj watershed.

- Increasing groundwater stored during monsoon: The survey showed that only 16% of the farmers perceived that the groundwater quality is deteriorating over the years. Therefore, recharge to groundwater will constitute recoverable fraction of inflow. However, the survey also showed that water harvesting is adopted by only 19% of the farmers. Despite a consensus among farmers that water availability is their primary constraint; on-farm water harvesting is not widespread. Groundwater is stored in aquifers which are not bounded by farm boundaries. Therefore, the benefits accrued by farmers recharging aquifers using on-farm-run-off water will not confine to their farm. Instead, they will lose crop production in the part of their farm, which is inundated to recharge the aquifer. Therefore, in general, farmers tend not to install and maintain groundwater recharge structures in their farms.
- Storage capacity of aquifers is the primary constraint. In all wells, post-monsoon groundwater levels were at or near the surface informing that the supply of water for recharge is greater than the storage capacity available in hard rock aquifers. Precipitation and runoff characteristics of the watersheds, storage characteristics of aquifers, and farmers demand for groundwater need to be harmonised. Alternatively, surface storage can be increased by taking advantage of undulating topography. Water stored in surface storages can be directly pumped by farmers nearby. They will also prolong opportunity time for infiltration and continue recharge as groundwater levels decline during post monsoon.
- Tillage and mulch management practices are not conducive to reduce non-beneficial evaporation, and conserve soil moisture for beneficial transpiration. Plausible reasons include a lack of appropriate machinery and demand for crop residues to feed livestock.
- Farmers’ appreciation for irrigation scheduling criteria is very poor. Farmers do not consider critical stages of crop or soil moisture deficit as criteria for irrigation. Visual symptoms of crop stress or access to groundwater influence their timing of irrigation. Training farmers and access to soil moisture measurement devices like tensiometers and gypsum blocks would be a valuable promotion in the region.
- Farmers recognise the need to minimise conveyance losses from the wells to the fields, which will result in reduced costs of pumping and recycling of groundwater. Programs to encourage plastic pipes to minimise conveyance losses will be well-received by the farmers.
- Changing to low-water demand crops to cope with temporal water scarcity is feasible only if it is profitable to do so.

7.3 Performance vs. Impacts of MAR

7.3.1 Context

To minimise and counter decline of groundwater levels and improve the availability of water for crop production, Managed Aquifer Recharge (MAR) interventions are widely adopted across India. These are often initiated or supported by, local communities, state and central governments. While the literature on MAR in India is vast, the science for their evaluation is lacking. There is an absence of a structured approach to evaluate the performance and impact of MAR interventions. Often, performance and impacts of MAR have been commented upon together, without distinguishing the two. Performance and impact are different from each other, and that the evaluation of MAR interventions should take into account such differences between them.

Performance refers to the accomplishment of a given task measured against pre-set known standards, and impact is a sustainable change or outcome brought about by a given intervention. The performance of MAR interventions influences impacts at primary, secondary and tertiary level. When a MAR structure performs to its intended objective, its primary impact is on the groundwater resources - the groundwater level is expected to rise and its quality is expected to improve. Enabling factors affecting the extent of primary impacts are hydrogeological characteristics such as geological boundaries, inflow and outflow of regional groundwater flow, porosity; transmissivity, natural discharge of springs, lithology, thickness of the aquifer, and tectonic boundaries.

The secondary impact of MAR results from the productive use of additional groundwater available. This may improve potable water supply, enhance agricultural production and even reduce energy consumption for lifting water. However, supporting factors such as convenience of quality seeds, labour, uninterrupted energy supply, fertilizers and land holding rights greatly influence the scale of the secondary benefits of MAR.

Tertiary impacts result from the use of the outputs from secondary impacts enabled by MAR interventions. By benefitting from the secondary impacts, they alter the socio-economic aspects of the society, provided, additional enabling conditions prevail. The quantifiable indicators of socio- economic impacts are increases in income through more water being made available for crop production and thus resulting in rise in gross value of production.

7.3.2 Key findings

An analysis of MAR evaluation reports

The framework for performance and impact analysis, based on three levels of impacts, viz. primary, secondary and tertiary, was applied to selected MAR interventions in India, viz., Adarsha watershed – Andhra Pradesh, Gokulpura - Goverdhanpura watershed – Rajasthan, Kodangipalayam watershed – Tamil Nadu, Chikalgaon watershed – Maharashtra, Rajasamadhiyala watershed- Gujarat, Satlasana watershed – Gujarat and

Sujlam Suphalam Yojana – Gujarat. None of them could explicitly demonstrate that reported impacts were uniquely linked to MAR interventions.

We note that MAR is only a component of a larger production/socio-economic system, and only by ensuring performance of MAR other intended impacts may flow. Therefore, we propose that the evaluation of MAR should be focused on its performance. If impacts are used as a surrogate for performance, it must be shown that impacts are uniquely linked to MAR interventions.

Ensuring high degree of performance of MAR

As defined earlier, performance refers to the accomplishment of a given task measured against pre-set known standards. In the pre-construction phase, the type of system to be designed for optimum performance depends entirely on local conditions of soil, hydrogeology, topography, water availability and climate. The potential standards during the pre-construction phase are design criteria such as: peak discharge, spillway capacity, storage capacity, and design infiltration rate. During the post-construction phase, standards may include percentage fill of total capacity and minimum damage to property from flooding. Other possible indicators include the incidence of clogging, damage occurred or maintenance required and the number of hours the intervention recharged during rainfall. Hence, the indicators of performance are related to percentage fill of total capacity, the degree of damage to property from flooding and reduction in the infiltration rate due to clogging and siltation over time.

Without water, there can be no MAR

MAR cannot ‘perform’, if there is ‘no’ water. Without water, MAR structures will remain empty, and the investments are wasted. On the other hand, MAR structures are required for regions where water is scarce. Therefore, a careful probability analysis of water availability is a pre-requisite to design MAR.

In semi-arid regions of India, water for MAR is very limited. The State of Punjab, India, between 1871-2000, had an average rainfall of 500 mm, and it ranged from 150 mm in 1987 to 1012 mm in 1971. The probability of receiving 150 mm rainfall is 0.99, but the probability of receiving 1012 mm rainfall is 0.01. The median rainfall of this state is 480 mm, suggesting that at least 50 percent of the time, the annual rainfall will be less than 480 mm. This state, being in the semi-arid part of India, has an average potential evaporation of over 1800 mm. Under such circumstances, it is highly unlikely that there will be runoff on a regular basis providing the possibility of MAR on an annual basis. How could then a farmer rely on MAR for water to support his crops on a daily basis?

Canal Irrigation infrastructure are MAR too

When canal irrigation infrastructure is developed in semi-arid regions, storage and conveyance losses recharge the aquifer. This water is subsequently pumped by farmers to improve irrigation water security. Recharged groundwater in canal commands has increased reliability of irrigation water leading to quantum leaps in agricultural productivity. In a recent study GRACE data and remotely sensed land cover data were used along with rainfall data to understand the groundwater recharge and discharge in Gujarat. The study found that even though there was not a considerable change in the annual rainfall patterns across the state of Gujarat, the small scale water infrastructure (especially check dams) and the increase of the height of the Sardar Sarovar dam by 10 m resulted in an increase in groundwater storage by 29%, when compared to years with similar rainfall before the introduction of the water infrastructure.

We need land for MAR

In north-western India, land is also a constraint for installation of MAR structures. Landholders are unwilling to provide land for MAR, because it would result in a loss of income, although recharged water would benefit the wider community. Public lands are scarce, and are often of unsuitable for installation of MAR.

Influence of soil type on performance of MAR

Soils above the aquifer could retain substantial volumes of recharging water. Following infiltration, water percolates through an unsaturated soil to recharge the water table. Energy gradient facilitates this process. The relationship between water content and energy status is unique for each soil as it depends on texture, particle size distribution, aggregation, and pore size distribution. This unique relationship is called the Soil Moisture Characteristic, or Water Release Curve, and expresses the matric potential energy as a function of volume water content. For example, at - 20 m suction, a silty loam profile of 1 m could hold 50 cm of water, while at the same suction, a sandy loam soil profile of 1 m could hold only 0.05 cm. Hence if a MAR structure is installed on top of a silty loam profile, recharge to groundwater will be low because percolating water will be retained by the profile. On the other hand, if the MAR is installed on top of a sandy loam profile, most of the percolating water will reach the water table.

Response to MAR depends on Geology as well

In India, two-thirds of the total surface of the country is 2 occupied by hard rocks; that is nearly 2.4 million km. Hard rock is a term coined by drillers to indicate poor drillability. They are characterised by insignificant primary porosity and primary permeability. Due to weathering and fracturing, such rocks contain secondary porosity and permeability which are not constant in every location. Fractures in hard rocks create porosity but for permeability, interconnectivity of fractures, fracture aperture and other such properties are very important. In general, effective porosity of crystalline rocks is less than 5 percent. On the other hand, porosity of alluvial aquifers (of sand and gravel) is in the range of 40-50 percent. Therefore, per unit volume of recharge, groundwater level in a hard rock aquifer will rise by about 20 units or more, but in an alluvial aquifer it will rise only two folds. It should also be noted that hard rock aquifers, having low permeability, will not transmit water widely, but they will release water stored easily when pumped.

7.4 Understanding the diversity of attitudes to groundwater

7.4.1 Context

Indian policies concerned with agricultural development have evolved from an initial focus on increasing food production to contemporary concerns for the environment, poverty and diversified livelihood options. Irrigation development continues as a primary factor in rural poverty alleviation by ensuring agricultural advances, expanding livelihood opportunities and employment both on and off farm. Access to groundwater has enabled farmers to better manage episodic deficiencies in monsoonal rainfall, avoid drought related crop losses and engage in dry-season irrigation.

India’s groundwater story is uniquely scripted by millions of farmers operating autonomously managed wells leading to an increasing level of groundwater anarchy. Maintaining groundwater dependent rural livelihoods without further reductions in already depleted hard rock aquifers continues as an increasingly critical dilemma facing irrigator communities in the Dharta and Meghraj watersheds. Access to cheap pumps, subsidised electricity, changing crop patterns and increasing population have increased the tensions between aquifer conservation and extraction.

7.4.2 Key findings

Aquifer rights and institutions

Informal rights to extract groundwater are conferred by well construction (costs are incurred by individuals) and land ownership (land ownership confers default rights to the aquifer below). Limited hydrological information available to village communities to establish sustainable aquifer limits and the absence of state regulations or markets to coordinate and constrain the operation of individually operated wells has led to an exploitative extraction regime that exceeds recharge potential.

Balancing sustainable aquifers with individual livelihoods, coupled with the absence of effective management has focussed attention on devolved administration and village level institutions to coordinate individual well owners and sustainably manage aquifers. Aquifers can be sustainably managed if information, communication and sanctioning options are available to aquifer dependent communities to craft their own groundwater management coordination rules, rights and sanctions.

Self-organised irrigation systems require clearly-defined boundaries; balanced accounting of benefits and costs; the ability of irrigators to set and modify rules; accurate aquifer monitoring; graduated sanctions; conflict resolution mechanisms and the external recognition of community rights.

Attitudes to groundwater management and village level institutions

Abstract constructions including economic calculus, political economy, hydrographs and crop yield analysis are prevalent in contemporary groundwater programs intended to promote village level management. Equally important and often neglected are the attitudes to groundwater management, and the local knowledge and aspirations of village communities. Successful community crafted groundwater institutions appeal to, and mobilise individually held attitudes and motivations that reinforce collective action, trust reputation and reciprocity, the critical precursor to sustainable aquifers.

Individually held attitudes about groundwater are important factors shaping behaviour, and actions that influence community institutions and aquifer sustainability. Understanding the diversity of attitudes towards groundwater management introduced an empirical basis to tailor participatory processes to assist communities to coordinate groundwater management and flag possible tensions.

During face to face interviews, irrigators answered 11 questions about how their water use affects other well owners, MAR, the condition of the aquifer and their attitudes to sharing water in the future.

- How likely is it that your children will take over your farm in the future?
- Do you think that increasing the depth of your well has had an impact on your neighbours?

- Will the current depth of well/tube-well be sufficient in the next 5 years for your current cropping pattern?
- Is MAR the best way to maintain your well?
- Is efficient water use the best way to maintain your well?
- Has your neighbour's groundwater use reduced the amount of water in your well?
- Would you be willing to share the water and costs of a recharge scheme with other farmers?
- Would you be willing to reduce the number of watering if it meant that water would be assured for your children?
- If your managed recharge scheme increases the water available for your neighbours, should they compensate you?
- If your neighbours managed recharge scheme increases the water in your well, should you pay them?
- Would you be willing to adopt a new groundwater management scheme that shared water and costs fairly amongst all irrigators in your village?

A diversity of groundwater attitudes

Four discrete and diverse groups or clusters characterised by different combinations of responses to the attitude questions were detected (Figure 7). The four clusters were differentiated by whether irrigators are future oriented or more focussed on the present, how optimistic they were of positive future solutions, the role of MAR in sustaining the aquifer and whether compensation should be forthcoming if wells are affected by the actions of other well owners (both positive and negative). Importantly the distribution of the four clusters was different across the two watersheds (Figure 8).

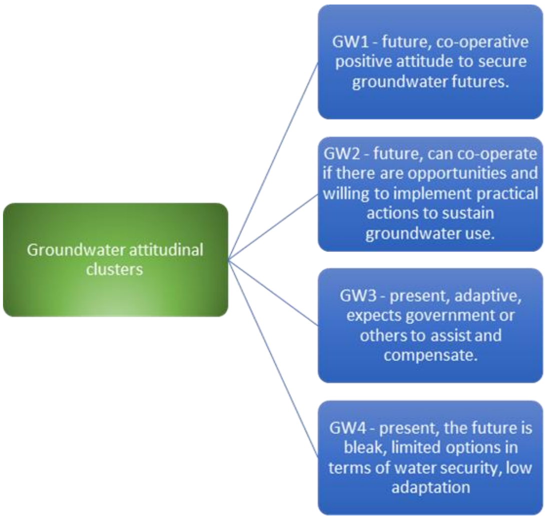

Figure 7. Characteristics of the four groundwater attitude clusters

The results question the effectiveness of a uniform approach to assist communities craft rules and strategies to reduce over-extraction of groundwater at the village level. Individual attitudes about aquifer connectivity, willingness to amend well operations, water conservation and time orientations vary across villages and watersheds. Importantly understanding the structure and distribution of attitudinal diversity means programs can be tailored to match village attitudes. Tailored programs to assist communities craft their own institutions improve the likelihood of sustainable aquifers and reduces the risk of program failure. Incomes, assets and farm size are also significantly different across the four attitudinal clusters, factors that may influence the willingness and capacity of individuals to engage in groundwater negotiations.

The research is intended to guide a resilient foundation for farmers, so that they can continue to use local groundwater resources and engage in public participation to assess aquifer conditions and inform Village Groundwater Co-operatives, even after project partners leave the project.

The social attitudes and behaviour research combined with new groundwater knowledge has led to development of a palette of locally relevant groundwater management strategies that will;

- enable broad based community support and be effective;
- account for cost effective supply enhancement and demand reduction that accounts for downstream water requirements;
- be fully understood by villagers because of the observation based generated by the efforts of BJs;
- need to be implemented and tested in operational mode, and with government or NGO support mechanisms in the longer term (say >5 years); and
- need to be extended via the same action-reflection learning approach to other villages in over-drafted areas.

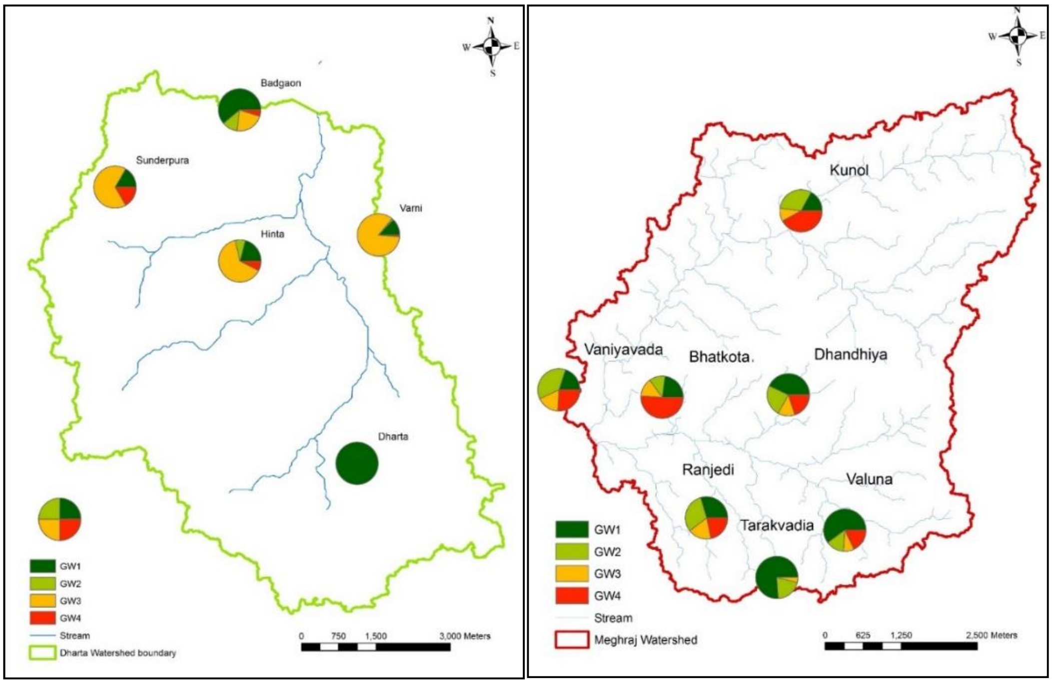

Figure 8. Cluster distribution in the Meghraj and Dharta watersheds

7.5 Groundwater and wellbeing

7.5.1 Context

Indian policies concerned with agricultural development have evolved from an initial focus on increasing food production to contemporary concerns for the environment, poverty alleviation and diversified livelihood options. Improved wellbeing for individuals and communities are either the explicit or implicit priority objective of the current suite of groundwater related policies. Surprisingly, given the importance of wellbeing in policy formulation, efforts to understand what constitutes wellbeing when viewed from the perspective of farmers has received minimal attention.

Maintaining groundwater dependent rural livelihoods without further reductions in already depleted hard rock aquifers continues as an increasingly critical dilemma facing irrigator communities in the Dharta and Meghraj watersheds. The escalating tension between jointly sustaining livelihoods and aquifers is not confined to the two watersheds but is widespread throughout India's agricultural hinterland.

The groundwater dilemma reflects increasing demands to develop systems that jointly measure and meet the imperatives of improved wellbeing and sustainable use of aquifers in India. Such a system must, of necessity, be multi-dimensional, focus on the household and capture individual life evaluations and priorities.

The MARVI project has relied on participatory based approaches as a necessary step to assist groundwater dependent communities in the Meghraj and Dharta watersheds to develop village level institutions to coordinate individual well owners and jointly achieve sustainable aquifer management and improve their prioritised wellbeing factors and dimensions. Participatory processes were central to the development of the vector of subjective wellbeing factors posed to the irrigator in a randomised survey of irrigators and farmers.

Through a series of 760 face to interviews, we sought to answer three questions: (i) what are the priority factors of subjective wellbeing perceived by irrigators in the in the Dharta and Meghraj watersheds; (ii) are wellbeing factors consistent across watershed and village levels and (iii) are wellbeing factors consistent across households who hold similar life guiding values and attitudes to groundwater management? The latter question sought to answer the sustainability/wellbeing interaction.

7.5.2 Subjective and objective wellbeing

Objective wellbeing represents the 'externally approved, normatively endorsed, non-feeling features of a person's life; income is common measure. We relied on subjective wellbeing as an information based appraisal of how one's life measures up to expectations and resembles an individual's envisioned "ideal life". There are three main concepts of wellbeing: wellbeing as pleasure; wellbeing as the fulfilment of preferences/desires; and wellbeing as the attainment of one of multiple factors in a list of what makes a life well-lived.

Subjective wellbeing lists include social, cultural, material, economic, natural resources and human dimensions, combined with variables eliciting intermediate needs not met (for example food, housing, health, education and family relations). The list of 38 factors that comprise subjective wellbeing in the watersheds represent economic, social and environmental dimensions and were derived through consultation with the irrigator communities and wellbeing lists used previously with over 7000 rural households in south east Asia.

7.5.3 Key findings

Measurement levels matter

We quantified individual wellbeing by combining their perceived importance and satisfaction level of each of the 38 factors into an Index of Dissatisfaction (IDS). A high IDS score is therefore associated with high levels of importance, a high proportion of selection and high levels of dissatisfaction.

A wide range of wellbeing factors were selected in both watersheds (Figure 9). Income, land ownership and access to health services were seen as the factors that were selected as most important and farmers were most dissatisfied in Meghraj; soil quality, water quality and family relations were the most important and dissatisfied wellbeing factors in Dharta. The mainly economic wellbeing factors characteristic of Meghraj farmers were substantially different from the environmental wellbeing factors evident in Dharta.

The study indicated that water and soil quality in the Dharta watershed and income, land security and health services in the Meghraj watershed are the factors that will gain the highest levels of improved wellbeing. **Implementing uniform wellbeing policies that fail to address these differences is likely to achieve inferior wellbeing improvement.** An important finding was that there was a very low (less than 0.2) correlation between actual household income and farmer's level of dissatisfaction with income: both low and high income individuals were dissatisfied with their income. The policy implication is that a single reliance on improving household income does not equate to improved wellbeing in the watersheds, although this is less so in Dharta.

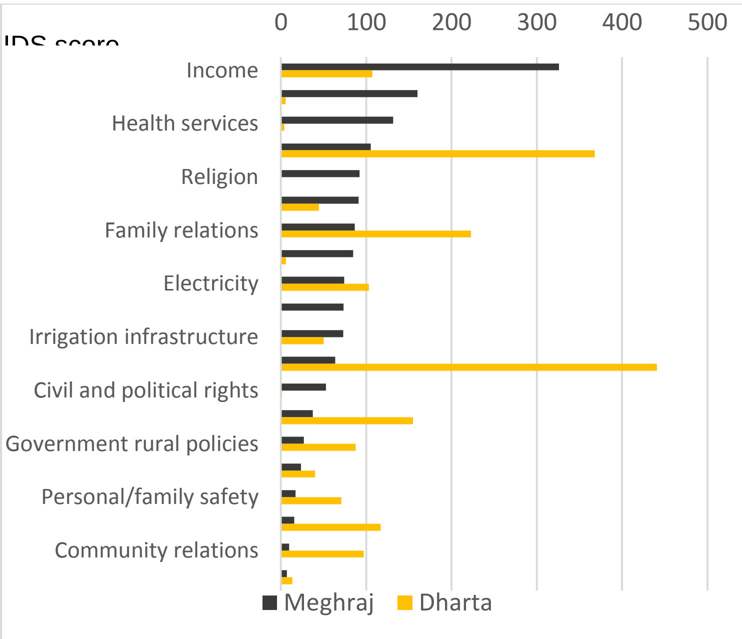

Figure 9. The variation of IDS with different parameters in the two watersheds.

Combining wellbeing measures with sustainability

We addressed the sustainability/wellbeing nexus by including adaptation, values that guide people's lives, farm attributes such as area and income, and attitudes to groundwater management in the statistical analysis. We found significant differences in these combinations within and between both watersheds and villages.

If improved wellbeing is the primary or sole objective, assistance programs could be designed to align with a relatively consistent set of wellbeing factors across all villages

located in each watershed. However, if sustainable groundwater and improved wellbeing are joint objectives, programs may need to be developed at the village level, not the whole watershed, to account for the diversity of observed attitudes to sustainability and wellbeing priorities.

As a final step, we developed a template to systematically guide the design of participatory processes to assist communities craft institutions with a potential to jointly meet sustainable aquifers and improved wellbeing. Table 2 lists different factors for two of the 11 villages, viz., a) priority subjective wellbeing factors, b) adaptation intentions, c) acknowledgment of well interdependence and aquifer connectivity, d) attitudes to groundwater management and d) the most trusted assisting and coordinating agencies.

	Badgaon	**Dharta**
Subjective wellbeing	Water, soil and family	Water, soil and family
Adaptation	Low	Low
Acknowledge aquifer connectivity	Yes (neighbour)	Yes
Own well impact	2%	97%
Neighbour well impact	80%	100%
Willing to cooperate and share costs	98%	97%
Current water conservation	Low	Low
Willing to reduce waterings	78%	100%
Time orientation	Future	Future
MAR or water efficiency	Both	Both
MAR Compensation	85%	100%
Overall trust	High	Mid
Most trusted agency	Family	Family
Least trusted agency	Scientists farmer groups	Scientists farmer groups
Preferred assisting agency	Community/Panchayat	Community/Panchayat
Preferred coordinating agency	Well owners/ community	Well owners/ community

7.6 Groundwater Scarcity and Educational Opportunities for Female Students

7.6.1 Context

India declared in 2010 that education is a fundamental right for every child up to the age of 14. However, numerous challenges and constraints exist in attaining this goal. In particular, gender disparity remains a critical issue for human development in India. The female students in India average less than four years of education in a lifetime and 40% leave school before they reach the fifth grade.

While considerable progress has been made in male and female literacy rates in India during the past 60 years, there remains a large gender gap in the literacy rate, especially in Western India. For example, in Rajasthan the male literacy rate reached 81% in 2011, but nearly half the females remained illiterate in the state (Table 3). This is well below the average female literacy rate in India (65.5%). In Gujarat the situation is slightly better than Rajasthan but still a large gap between male and female literacy rate (16%) remains. Kerala has not only high literacy rate for males and females but the gender gaps is the smallest (4%).

Table 3: Male and Female literacy rate (%) in Western India based on 2011 Census (Arranged in decreasing order of female literacy. Kerala is included as a reference)

	Male	**Females**
India	82.1	65.5
Kerala	96.0	92.0
Maharashtra	89.8	75.5
Punjab	81.5	71.3
Gujarat	87.2	70.7
Haryana	85.4	66.8
Rajasthan	80.5	52.7

To assess if the water security issues and associated factors are impacting on the educational opportunities of female students we conducted a survey in two watersheds of western India (Gujarat and Rajasthan) under the MARVI project. We examined how demands on students' time through their household responsibilities, viz., fetching drinking water by females and providing help in farm activities by male students is related to school absenteeism based on three years of school attendance record. A stratified random sampling method was adopted to select the respondents from year 8 to 12 classes in nine schools in total, with 40-50% students surveyed being in year 8 class.

The study area in Gujarat is located in the Sabarkantha district of the Meghraj watershed, which is predominantly a tribal area with approximately 30% of the population belonging to the socially and economically disadvantaged. The study area in Rajasthan is situated in the Udaipur district. This district is in the southern part of Rajasthan, surrounded by the Aravali hills. In both watersheds, groundwater irrigation plays an important role in agriculture and the livelihood of people.

7.6.2 Key Findings

Educational status of students mothers and fathers

- In Gujarat, 41% of the mothers of interviewed students did not receive any school education, whereas in Rajasthan the number was as high as 58%. While none of the mothers had received tertiary education in Rajasthan, only 3% of the mothers were tertiary educated in the study area of Gujarat.
- Literacy rates in males (fathers of students) were much higher than females (mothers) and only 5-9% had not gone to schools. Clearly gender disparity in terms of educational background in the two region was clearly evident even in this small survey.

Students awareness about groundwater situation

- The students were found to be highly aware of the existing water scarcity issues in their respective watersheds. (Table 4).
- Approximately 88-96% of students in both of the surveyed watersheds had identified groundwater scarcity as a major challenge.
- About 80-90% of the students suggested solutions that included reducing water wastage, reducing demand, increased water harvesting and building ponds.

Household chores and school absenteeism

- Approximately, 94% of the surveyed students were involved in household work, with female respondents helping with fetching drinking water from a nearby well, cooking, cleaning the home, looking after younger siblings.
- Approximately 68% of the surveyed students in Gujarat arrived late or left school early due to household duties while 65% of students missed school altogether. Of those students missing school, nearly two thirds missed school up to two days in a month, and some (27%) up to 4 days per month (Table 4).
- In Rajasthan, there was a reluctance to answer the question but approximately 24% of students reported missing school up to 2 days a month.

Table 4: Demand on students for home/farm duties and its impact on school absenteeism. N.B. Data is presented as % respondents of total number surveyed opting for the specific category.

Home/farm duties and absence from school	Meghraj	Dharta
Help at home given	94	97
Arriving late or leaving school early	68	61
Missing school altogether	65	40
1-2 days/month	64*	60*
3-4 days/month	27*	7*
>4 days/month	9*	33*
Unhappy arriving late or missing school	84	86

* of those who missed school

Gender and school absenteeism

- A clear link between gender and school attendance was noted. For example, in Gujarat while some 40% of male students missed school, the number of females missing school due to home duties was nearly twice as much (77%).
- The school attendance records procured from three schools in the Dharta watershed over a period of three academic years (2011-2013) showed that on average there are more female students absent in a given month compared to males. The difference was statistically significant.
- The median values for school absenteeism in the Dharta watershed were 3.6 days per month for females in contrast to only 2.2 days per month missed by males. Again 34% of female students missed > 5 days of schooling per month whereas only 15% of males were into this category. (Figure 10).

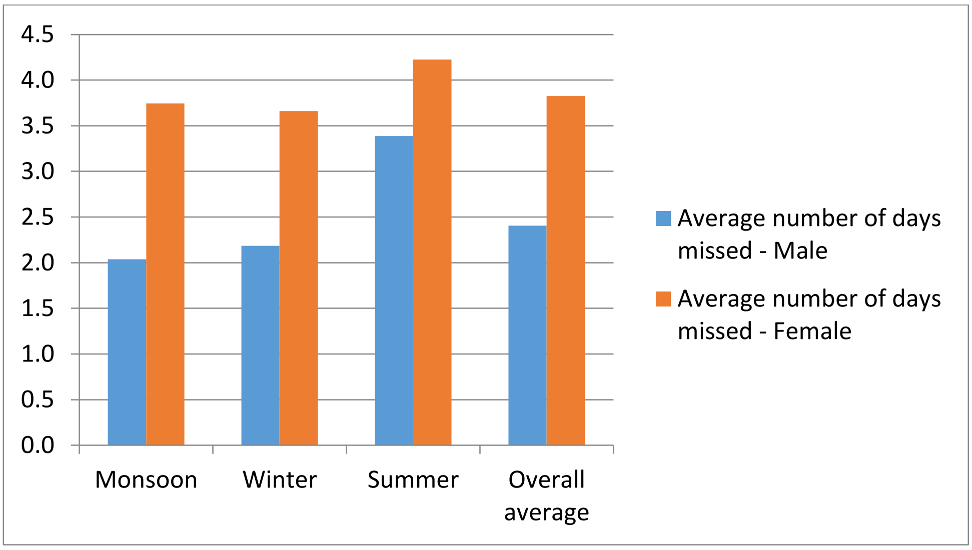

Figure 10. Average number of days (per month) missed by year 8 students during different seasons (2011-13) in three study areas.

Parent's view about causes of school absenteeism

- A socio-economic survey on Gender conducted at the same time in the MARVI project (Varua et al. 2015) revealed that 100% of the task of drinking water collection was assigned to women.
- A vast majority of parents (< 50 year) in the two watersheds (67-81%) acknowledged that the water collection indeed disrupted their daughter's education, in contrast to none identifying the disruption of their son's education.
- Approximately 60% of the of surveyed parents indicated that their daughters have either missed school or were late in going to school because they were helping them collect water for domestic use.
- Approximately 80% of the parents indicated that better access to drinking water will enable their daughters to spend more time on their studies.

Empowerment of women and inclusive educational opportunities

The current study indicates a possible link between school absenteeism and water scarcity, one of the most serious livelihood constraints in semi-arid regions of India (including Rajasthan and Gujarat), and is critical in achieving Millennium Development Goals in poverty alleviation and rural development, as well as those for water and sanitation.

The economic and social benefits of educating female students are similar or probably even greater to those of educating male students because of their role in both the household and farm and also because women's educational achievements have positive ripple effects within the family and across generations. Improving female education is one of the most effective ways to reduce poverty and thus appropriate policies and initiatives need to be put in place along with effective groundwater management to empower women in village communities.

7.7 Spatial Variability in Groundwater Recharge

7.7.1 Context

Undoubtedly, groundwater irrigation in India has enhanced farmer livelihood over the past few decades, resulting in substantial socio-economic benefits but it has also led to complex groundwater sustainability and management challenges. Rajasthan, a north western state of India, is heavily dependent on groundwater for irrigation and about 90% of the drinking water and 60% of the irrigation water is sourced from groundwater supplies. During the 1970s and 1980s, the era of Green Revolution in India, there was widespread use of groundwater in Rajasthan and the pressure on groundwater is further increasing due to population growth and an increased number of industries. About 80% of the State areas have witnessed groundwater depletion and many towns and villages have experienced a shortage of drinking water, particularly in the summer months (Rathore 2005).

Ongoing watershed development programs, due to paucity data and information on long term groundwater levels and aquifer properties, mostly follow a one size fits all approach, wherein specific artificial groundwater recharge methods (e.g., checkdams and bunds) have been distributed. These methods might have been successful in one region, however, they might not be the best option for the current study area. As a result, the performance and impact of the recharge method is limited, and may lead to a loss of capital investments, as noted in many regions of India.

The hydrologic properties of aquifers differ spatially due to variations in geologic setting, climatic factors, water demand/use and natural recharge. Therefore, a specific groundwater recharge method that worked wonders in one location (e.g. flood prone eastern plains of Rajasthan) might not work as well in another region (e.g. humid southern plains). As a result, it is necessary to conduct studies and surveys before installation of any type of artificial recharge method. In most cases, availability of data might be the most limiting factor for such studies, however, by using remote sensing and long term rainfall methods, spatial variability in groundwater recharge can be assessed (Chinnasamy et al 2016).

7.7.2 Key messages

Demarcation of Agroclimatic Zone area in Rajasthan:

Government of India has already demarcated the agroclimatic zones in Rajasthan through the National Agricultural Research Project (NARP), based on soil type, temperature, rainfall (agrometeorological characteristics) and geologic constraints. Future MAR investigations should take into account the properties of these agroclimatic zones, before investing (Table 5).

Rainfall trend across the regions

Based on the annual average rainfall data from 2004 to 2013, the humid regions have higher rainfall, followed by the flood prone and arid regions (Figure 11). Therefore, more rainfall can be harvested by proper measures in these regions.

Table 5. Different agroclimatic zones in Rajasthan.

Agroclimatic Zone	Area (km^2)
Arid western plains	51,237
Flood prone eastern Plains	26,560
Humid southern plains	8808
Humid south eastern Plains	24,170
Hyper-arid partially Irrigated zone	82,475
Internal drainage dry	25,450
irrigated north western plains	20,660
Semi-arid eastern plains	30,256
Sub-humid southern Plains	42,706
Transitional plain of Luni basin	51,013

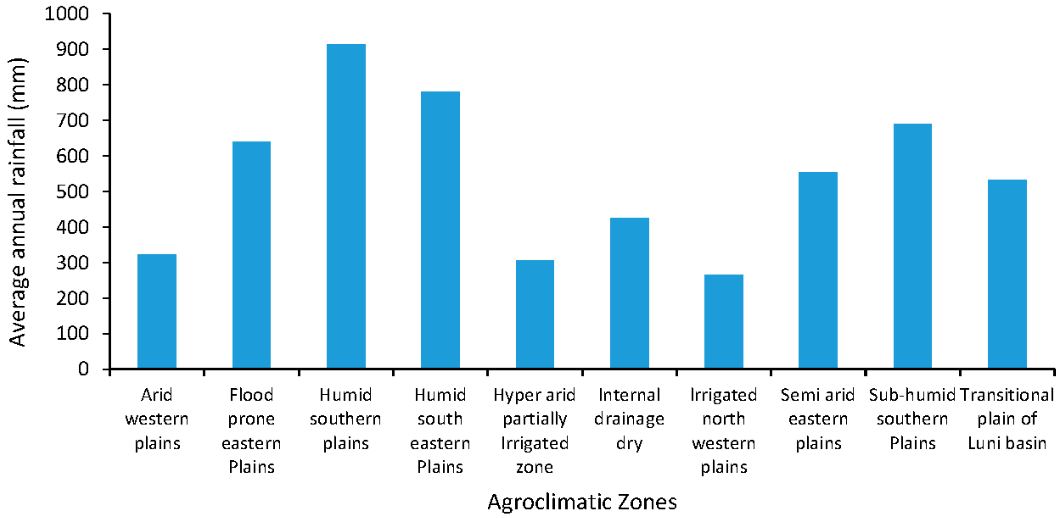

Figure 11. Agroclimatic Zone average annual rainfall hyetograph in Rajasthan from 2004 to 2013.

Net Groundwater Recharge

There are considerable differences in net groundwater recharge potential between the different agroclimatic zones (Figure 12). This urges the need for better characterisation of the region before implementing MAR activities, which will enhance MAR performance and impact.

One Size Fits All Approach

From the above exercises and results, it is understood that a specific groundwater recharge method that was successful in one location need not work as well in another region, and hence, site specific studies need to be undertaken before identifying the suitable type of groundwater recharge methods (Maheshwari et al 2014).

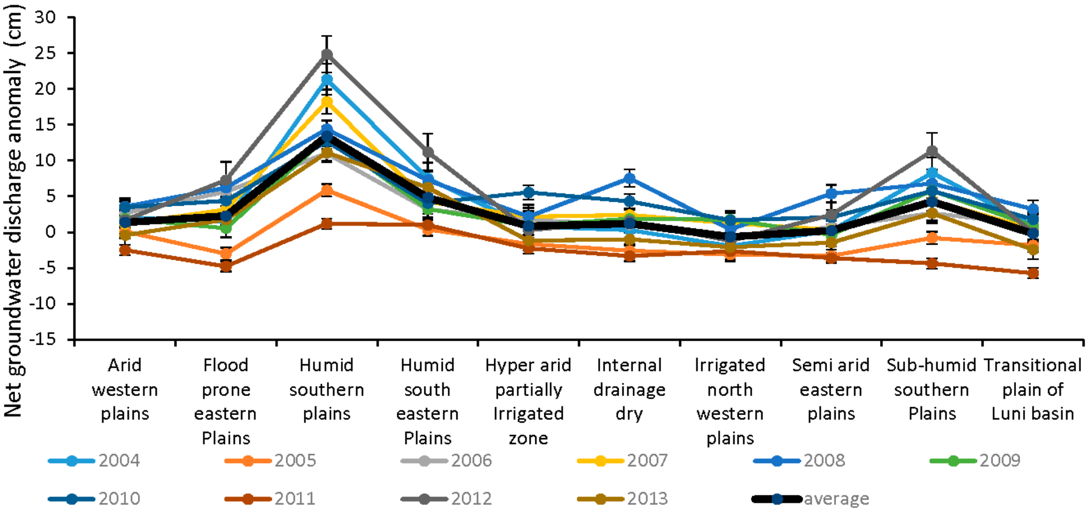

Figure 12. Variations in agroclimatic zonal GRACE estimates of net annual groundwater storage discharge (June–October) in the Indian state of Rajasthan. Bars indicate standard error.

Future Directions

Future studies should collect all relevant data that can be used to setup conceptual models before identifying recharge methods. Such models (e.g. mass balance equations, computer simulation models) can be tested with available data to assess aquifer recharge method's impact, performance and maintenance costs.

7.8 Assessing key aquifer properties

7.8.1 Context

India is the world's largest groundwater user with a usage of 230 km^3 per year (CGWB 2013). Groundwater has become a critical natural resource with great economic value in both rural areas. Groundwater has been recognised as the major source of irrigation water in India, particularly in states with inadequate supplies from surface water sources and with limited rainfall (Maheshwari et al.2014). Undoubtedly, groundwater irrigation in India has enhanced farmer livelihood over the past few decades, resulting in substantial socio-economic benefits but it has also led to complex groundwater sustainability and management challenges.

Effective groundwater management requires an estimation of annual recharge and groundwater volume that can be pumped from a given area, for which, we need a reliable estimate of aquifer properties such as specific yield and other hydrogeological information. In particular, the estimation of specific yield has been difficult in hard-rock aquifers and detailed and sophisticated measurements of groundwater balance components in a developing country situation is often difficult and beyond the financial resources of most government agencies.

7.8.2 Assessment of specific yield using a water balance approach

Due to the property of hard-rock aquifers, there is often large spatial variation in aquifer hydraulic parameters. This is further complicated by the variation in aquifer material types and properties with depth from the land surface, particularly evident when there are significant changes in the watertable during monsoon and pumping seasons. Therefore, the aquifer properties based on methods traditionally used in alluvial aquifers, e.g., pumping test method, may not provide representative values of the aquifer properties in hard-rock areas (Machiwal and Jha 2014).

The Central Groundwater Board recommend the use of the water balance method and water table fluctuation methods to estimate specific yield in India's hard-rock regions, especially in shallow water tables and unconfined aquifers (CGWB 2013). For estimating specific yield in hard-rock areas, the methods based on groundwater level data tended to yield more reliable values (Machiwal and Jha 2014).

7.8.3 Case study in Dharta watershed of Udaipur District, Rajasthan

The farmers in the watershed grow cluster bean, groundnut, soya bean, maize, black gram, mung-bean, guar and vegetables as Kharif crops during the monsoon season. Wheat, gram, sorghum and mustard are the main Rabi crops grown during the winter season. Farmers with groundwater and surface water access (e.g. canal water) grow two crops a year, while a limited number of farmers with year round water grow some summer crops such as vegetables and fodder. Most farmers in the watershed are from mainstream groups.

The groundwater head change during the Rabi season indicated that the Sunderpura village recorded the maximum average change of 12.37 m, followed by Dharta and Badgaon. Hinta-Varni region had the lowest groundwater change of 5.62 m, even though the cropped area is highest in this village. Once the crop water use (i.e. net storage change) and head change were estimated, the specific yield was estimated using equation:

$$S_y = \frac{IWU}{A*\Delta h_m*100}$$

where, S_y is the upper bound specific yield (%), A is the area of the village (m^2) and Δh_m = average head change over the cropped area (m). The above method is used for two Rabi seasons: November 2012 - March 2013 and November 2013 - March 2014.

7.8.4 Key messages

- **Specific yield (S_y) as a function of crop water use and water table fluctuation -** Estimates of S_y in the five villages were between 1.4 and 8%. The watershed's area-weighted average S_y was 3.8%.
- **Spatial variation of Specific yield -** The results showed that there was statistically significant variance in the S_y between the village sites, indicating that the geophysical characteristics that influence the S_y are different between the villages. Therefore, due to spatial variability, site specific aquifer recharge methods need to be researched before implementing. This result also indicates that the amount of water that a farmer can withdraw is regulated by the geophysical properties of the site and the water pumping nature in the surrounding environment.
- **Temporal variation of Specific yield -** The results showed that there was no statistically significant variance in the Sy between the two experimental years, indicating that the processes that influenced the Sy did not change significantly between years. This was due to the fact that the rainfall and cropping pattern did not change much between experimental years. Therefore, the results indicated that the Sy varied spatially but not temporally.
- **Factors influences specific yield in agricultural areas -** The *IWU* (Irrigation Water Use) had the most influence on the S_y, i.e. highly sensitive, while the village area (*A*) and change in head (Δh_m) had impact on S_y, but lesser than the IWU.

- **Consistency with previous studies -** Similar to previous studies, the S_y values indicate the complexity and heterogeneity that exist in hard-rock aquifers. It is to be noted that Machiwal and Jha (2014) estimated the S_y (using double water-table fluctuation method) to be between 3.8 to 0.2 % for a study area in Udaipur district, while the current study result indicates an average specific yield of 2%, with some spatial variations related to water table depth and groundwater use patterns.
- **Future Directions –** The water balance method developed and tested in this study can be used to estimate Specific Yield (S_y) for small scale studies with less data. In addition, this method can provide site specific S_y for computer simulation models that require better estimation of the spatial variations in groundwater aquifer properties.

7.9 Gender and Groundwater Management

7.9.1 Context

Over the past three decades, women’s issues have gained prominence on the international and national development agendas. More evident in India where the plight of poor and marginalised women has been central to the formulation of government policies. To better understand the reality of gender in relation to ground water management and use, a series of 85 face-to-face interviews were conducted in Meghraj watershed in Aravalli district, Gujarat, and the Dharta watershed in Udaipur district, Rajasthan located in India.

7.9.2 Key findings

Household division of labour

The daily activities shared between men and women are summarised in Table 6. The results suggest that women are the primary decision makers for household water collection. For example, more than 75% of the women interviewed indicate that they are solely responsible for deciding when and how much water to collect. The focus group discussion further reveals that women who are not involved in water collection themselves are responsible for directing other women in the household to collect water. The results indicate that most of the domestic work is conducted by women and that water collection is 100% a woman’s task.

In contrast to policy deliberations and prevailing perception that the primary role of women is confined to that of domestic users of water, the results of the study show that women also make substantial use of water for productive purposes such as in caring for animals and growing vegetables.

Women and Water Collection

The study confirms that a large number of women continue to travel many times a day to collect water for various uses (see Figure 13). Women travel an average of 3 times in a day for 50 to 77 minutes per trip to collect drinking water, depending on the season. Improved access to a reliable and proximate water supply reduces the time spent by women in collecting water and the proportion of hard labour performed by women. Respondents indicate that improved water access will enable them to pursue other livelihood activities that will increase their income earning potential and help strengthen their bargaining position.

Table 6: Share of Activities between Men and Women (in %).

	MEGHRAJ		DHARTA	
	MALE%	FEMALE%	MALE%	FEMALE%
Type of Housework				
Cleaning the house	0	100	0	100
Cleaning the family's clothes	0	100	0	100
Caring for children	38	100	22	100
Caring for the sick and elderly	25	100	33	100
Cooking and preparing food for the family	0	100	0	100
Water collection – by hand	0	100	0	100
Deciding when to collect water	25	75	18	82
Preparing fuel	13	100	13	100
Fixing fences and house material	38	88	71	80
Herding animals	13	100	20	96
Feeding animals	5	100	13	100
Milking animals	0	100	0	89
Growing vegetables	50	100	93	84
Preparing goods for market (crafts, food or animal products)	100	25	100	4
Purchasing household food	100	13	100	4
Purchasing household goods	100	5	100	0
Working outside at a regular job for extra income	63	8	67	7

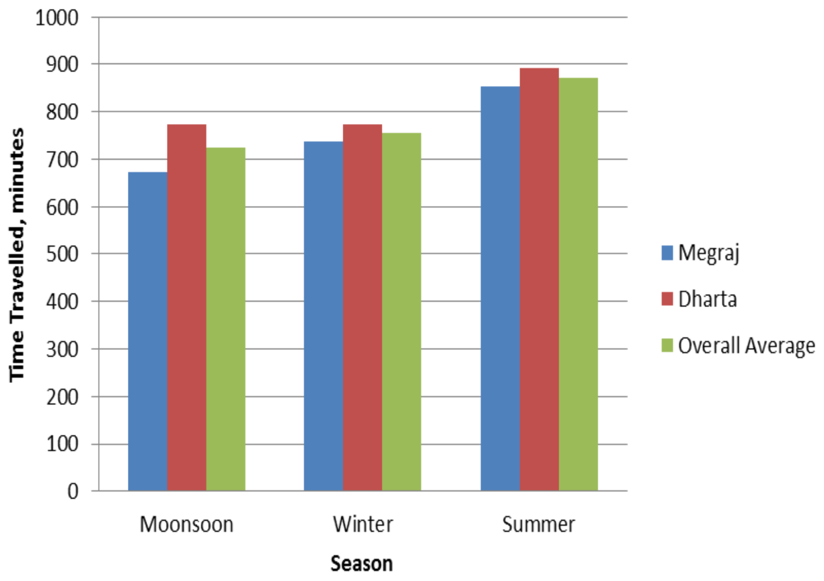

Figure 13. The variation of time travelled by women to collect drinking water with season in Meghraj and Dharta.

Using the replacement method and assuming that the wage rate is 750 Rp per day for seven hours of work, further assuming that women are restricted to spend a maximum of an hour per day collecting water then the extra income a woman can earn each day during monsoon in Meghraj and Dharta is Rs 56 and Rs 64 respectively. In summer time, the extra income earned is estimated to be around 244 Rs/day in Meghraj and 264 Rs/day in Dharta. However, this figure is estimated using the average wage rate. This value may vary depending on the particular enterprise women may engage with during the freed hours.

Women's perception on water use, availability and quality

Most of the respondents collect their drinking water from a public tap or from an open well. More than 80% of them indicate that water is available for drinking, domestic use and agriculture most of the time (see Table 7). However, many reveal that water is not available for animal use all year round. For many of them, livestock is a source of income and food and are critical in maintaining strong socio-cultural linkages in these villages.

School absenteeism of female students

Respondents disclose that water collection disrupt their everyday life. All of them indicate that that water collection does not affect their son's schooling but around 60% reveal that it affects their daughter's or granddaughter's schooling. Figure 14 shows that more students are absent during the summer season and that female students are absent on more days than male students, findings similar to that of Kookana, *et al* (2016). In most rural communities within developing countries, it is primarily the women and girls who are responsible for collecting, storing and managing water. They also report that their daughters not only helped in the collection of water for drinking but also for other domestic activities and livestock use.

Table 7. Percentage of respondents who answered yes.

Description	Megraj	Dharta
	%	%
Is water available for........?		
Drinking	100	100
Domestic	77	98
Agriculture	85	91
Animals	70	82
Does water collection......?		
Disrupts family daily life	100	100
Disrupts Son's education	0	0
Disrupts Daughter's Education	71	65
In your opinion, is your drinking water quality.....?		
Good	67	65
Satisfactory	23	33
Poor	10	2

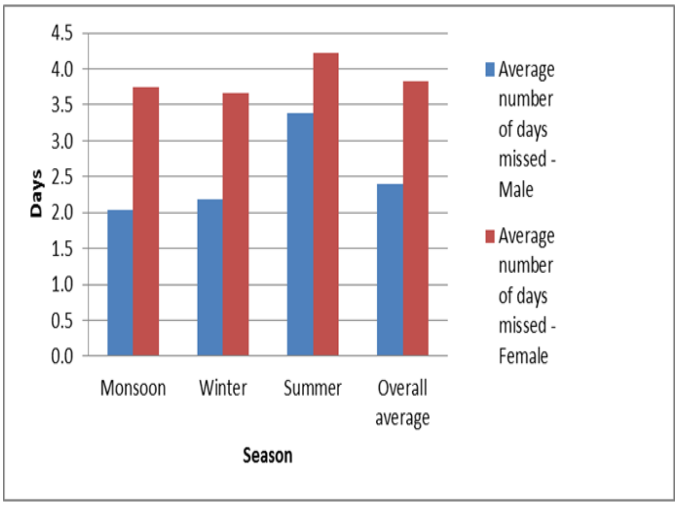

Figure 14. Average number of school days missed by male and female students during different season.

Women's perception regarding opportunities for advancement

Table 8 shows that the majority of women believe that men have more opportunities to be elected in government office than women in spite of the fact that Indian voters have elected women to numerous state legislative assemblies and the national parliament for many decades. On the other hand, women indicate that they have more prospects of being involved in non-government associations than men. They also believe that men and women have equal chances of being selected on a water management committee. Although women are actively participating in non-government organisations and water management executive committees, their influence in the decision making process is perceived by most women as not on par with their men counterparts. Thus, the mere physical presence of women in the water management activity cannot ensure that the plight of women is heard nor ensure their participation in the implementation process of water management initiatives.

Table 8: Perception regarding opportunity for advancement (in %).

	Megraj			Dharta		
Item\age group	<30	30-50	>50	<30	30-50	>50
Going to school – getting an education	1	1	3	1	1	3
Decision regarding children's higher education	1	1	1	1	1	1
To get a job	1	1	1	1	1	1
Decision when to move	1	3	1	1	3	1
Decision when to dig a new well	1	3	3	1	3	3
Being elected in political office or people's representative	1	3	1	1	3	1
Be involved in Non-Government organisations	2	2	3	2	2	3
Be involved in water management committees	3	3	3	3	3	3
*Reports the category with the highest response rate (mostly higher than 70%)						
Legend: 1 Men have more opportunities 2 Women have more opportunities 3 Women and men lave equal opportunities						

7.10 The Role of mulches, improved varieties and organic manures in managing groundwater demand

A major proportion of Indian agriculture is heavily reliant on groundwater irrigation. Beginning in the 1960s, with the onset of the Green Revolution, India saw a significant increase in groundwater Irrigation and it is vital for crop production, food security and livelihood of farmers. The demand for groundwater keeps increasing due to rising population, urbanisation and industrial usages. Farmers and all other users can play a pivotal role to increase groundwater productivity by adopting effective water management and agronomic practices.

Maize is a major Kharif season crop that is dependent on rainfall. Farmers apply supplementary irrigation using groundwater if monsoon rains fail at a critical crop growth stage. This irrigation often saves crops from complete failure. There are other simple and well proven water conservation measures that can be implemented by farmers to increase kharif crop yield and water productivity. Our field trials conducted at farmers' fields, as part of the MARVI project, during 2014 and 2015 Kharif season, elucidate how the use of mulches, improved crop varieties and organic manures can help the farmers to boost their maize yield, water productivity and can contribute to sustainable use of groundwater.

- Use of straw mulch in maize led to 26% increase in maize grain yield in comparison to no mulch use.
- Straw mulch markedly improved water productivity of maize. Under straw mulch, maize needs 1307 litres of water to produce one kg of grains. Without straw mulch maize required 1643 litres of water to produce one kg of grains.
- Straw mulch also helps in suppression of weeds and conservation of soil moisture.
- Hybrid maize cultivar Bio-9220 produced 49% higher grain yield over local *desi* maize grown by farmers.
- Hybrid maize has the ability to produce higher yields and better utilisation of groundwater. Maize cultivar Bio-9220 needs only 908 litres of water to produce one kg of maize grains. Local desi maize requires 1348 litres of water to produce one kg of maize grains.
- The application of farm yard manure (FYM) at 5t/ha and 10t/ha led to a 23% and 58% increase in maize yield.
- Application of FYM also increases water productivity of maize crop by 19% when FYM was applied at 5t/ha and 37% when FYM was applied at 10t/ha when compared with the control treatment (Figure 15). Also, it is also noted that under normal farmer practices in the study area the maize crop requires about 1700 L of water to 1 kg of maize with no application of FYM, 1400 L of water with 5t/ha of FYM was applied and 1100 L of water with 10t/ha of FYM.
- Organic manures are also an important source of microbial activities and micronutrients and help to improve the organic matter content of soil, which contributes to improve water-holding capacity of soils and enhances drainage particularly in clay soils. The use of vermicompost is another option to improve maize yields and water productivity but high cost of vermicompost can limit its usage.

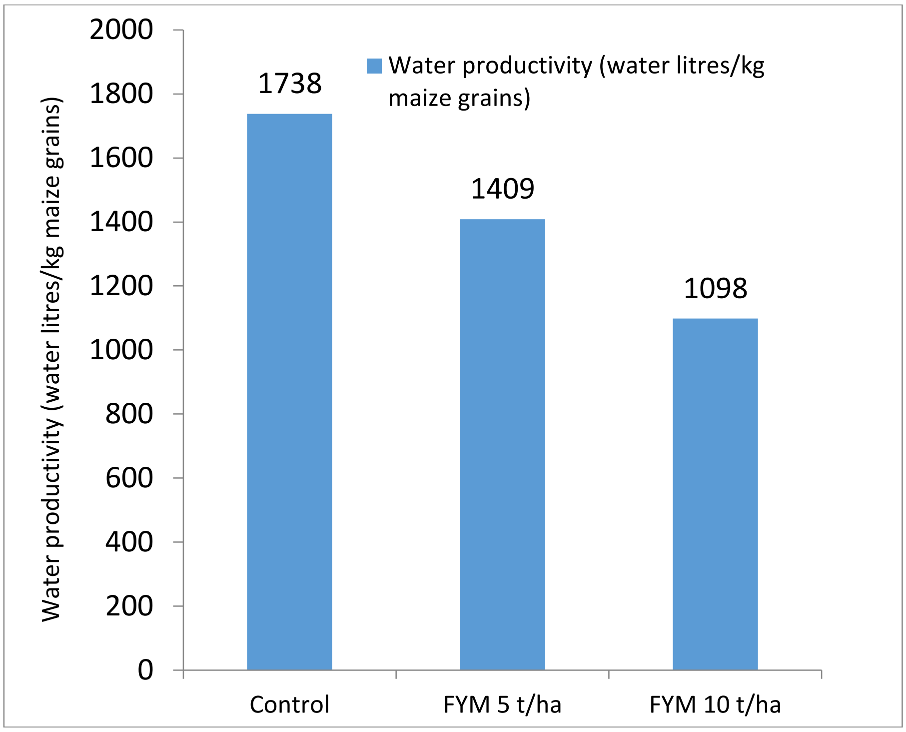

Figure 15. Effect of FYM application on water productivity.

Overall, the field study in the MARVI project has demonstrated that the use of straw mulch, hybrid maize and organic manures have great potential to improve maize yield and groundwater productivity. This also means, we need appropriate policies and support which will encourage the use of these well recognised agronomic practices by farmers to improve their income and livelihood and thus help them to achieve the efficient use of groundwater and help in 'more crop per bucket of groundwater' for their farms and villages.

7.11 Improving the productivity of groundwater: The role of zinc application

7.11.1 Context

Groundwater irrigation has played a pivotal role in increasing wheat yields and food security in India. Although there has been a substantial increase in wheat yields since the green revolution there are still marked yield gaps in wheat yields achieved at farmers' fields and yield potential of wheat varieties. Depleting groundwater, declining soil fertility due to intensive cropping are becoming major challenges to crops yields and water productivity. Farmers are intensively using nitrogen and phosphorus fertilisers to achieve higher yields from wheat but mostly overlook the importance of trace element like Zn and rarely use it.

To promote the use of Zn in wheat, we conducted a field trial at a farmer field in the Dharta Watershed of Rajasthan during the Rabi season of 2014/2015. The results elucidate how application of zinc along with nitrogen and phosphorus can help to improve wheat yield, groundwater productivity. Some of the key messages are:

7.11.2 Key findings

- Application of 5 kg zinc/ha along with 80 kg Nitrogen and 20 kg phosphorus/ha led to a 19% increase in grain yield when compared with no zinc fields.

- Use of zinc also resulted in a 42% increase in straw biomass which is a livestock feed and increase farmers income.
- Zinc application also markedly improved the groundwater productivity. Without N, P and Zn, 1934 litres water required to produce a kg of grains. With 80 kg/ha of Nitrogen, wheat needs only 1611 litres of water to produce one kg of wheat grains. Without zinc, but with N and P wheat requires 1469 litres of water to produce one kg of grains. With zinc along with N and P, wheat needs 1229 litres of water to produce one kg of grains.
- There was no beneficial effect of sulphur application on wheat grain yield and groundwater productivity.

The study clearly shows that Zn application along with N and P increases wheat water productivity.

7.12 MyWell – A smart phone app for participatory data collection and sharing

7.12.1 Context

The MARVI project is focused on developing a village level participatory approach, models and tools to assist in improving groundwater supplies and reducing its demand through the direct involvement of farmers and other affected stakeholders.

A unique feature of MARVI is the use of scientific measurements by citizens through the engagement of Bhujal Jankaars (BJs), a Hindi word meaning ‘groundwater informed’ volunteers. With appropriate training and capacity building, BJs monitor groundwater levels and quality, making sense from a village perspective of what is happening to village groundwater availability. BJs convey this information to farmers and others in their own language.

The depth to groundwater level represents the integration of recharge, pumping and flow processes and is a direct measure of groundwater availability and the success of any collective management practices. Therefore, the MyWell app can play an important role in estimating the availability of groundwater. In villages and making informed decisions about sharing and using local water sustainably.

Decisions regarding the sustainable management of groundwater should be based on objective science. By connecting farmers and local community members with hands-on monitoring opportunities we can begin a village level movement for groundwater security and produce and empower local groundwater champions.

Since 2012, the MARVI project team has worked in Rajasthan and Gujarat with farmers, schools and others in the village community to develop a village level groundwater monitoring approach. The idea of Bhujal Jankaar (BJ) was developed to assist in monitoring of groundwater levels around villages, collecting local data and developing a scientific understanding of groundwater dynamics. The data collected by BJs can inform sound decision-making about the sustainable management of groundwater.

Our aim was to demystify groundwater science at the village level and make it accessible to villagers, government agencies and NGOs, while ensuring that it is cost-effective, evidence-based and helps to assess the groundwater situation at village level and beyond. The unique approach used here through MyWell App provides villagers the opportunity to work alongside researchers and government agencies to collect local data and make them available widely.

The data collected through MyWell are critical to building our understanding of how the groundwater levels fluctuate during the monsoon and other times of the year when pumping is in full swing. Also, the local data collected this way can assist in understanding

how pumping impacts the groundwater situation at the village and beyond and inform sound decision-making about the management of groundwater.

Involving villagers in groundwater monitoring enables them to make a direct contribution to scientific research in their village, gain new insights based on actual data and learn ways to cope with groundwater scarcity. Also, involving villagers in groundwater monitoring provides immersive experiences that can help challenge current groundwater management practices.

7.12.2 MyWell

MyWell is a Smartphone and SMS App for collecting and analysing data related depths to well water level, rainfall amounts, checkdam water levels and water quality parameters. The App works by crowdsourcing data from MARVI project's network of BJs. MyWell displays the current status of the groundwater level in each well, together with rainfall amounts, checkdam water levels and water quality parameter values with historical and village level data for simple comparison and analysis.

MyWell approach

- Engage farmers, schools and local communities in groundwater monitoring;
- Help in easy collection and availability of groundwater and other related data across India; and
- Visualise groundwater data and empower farmers to self-manage groundwater sustainably at the village and Gram Panchayat levels.

7.12.3 How does the MyWell App work?

When a BJ takes a reading from a well, rainfall station or checkdam, they can use MyWell to submit it immediately. Either with a Smartphone or over SMS, all they need to do is type in their mobile phone the readings taken. This eliminates the need to use paper based systems, and allows for immediate feedback for the farmers relying on MyWell. Once a BJ saves a reading in the MyWell system, other MyWell users can access it at a later date for statistics and data analysis.

MyWell App is available for use on both Android and iOS platforms. The App has a host of tools for BJs to manage the MyWell system. BJs can register a new well, rainfall station and checkdam - using their device's inbuilt GPS to pinpoint the location.

MyWell also has a 'Banner Image' feature. Each well can have a unique Banner Image - usually of the well and farmer - allowing for greater personalisation and attractiveness to farmers.

As shown in Figure 16, the App allows farmers to see the trends in groundwater levels, rainfall and check dam water level on monthly, three monthly and yearly basis for available historical data for their individual wells, for the entire village and for the entire PIN code. The visualisation of the trends in collected data and further analysis can help farmers to compare different years for groundwater availability and plan for the next Rabi crop.

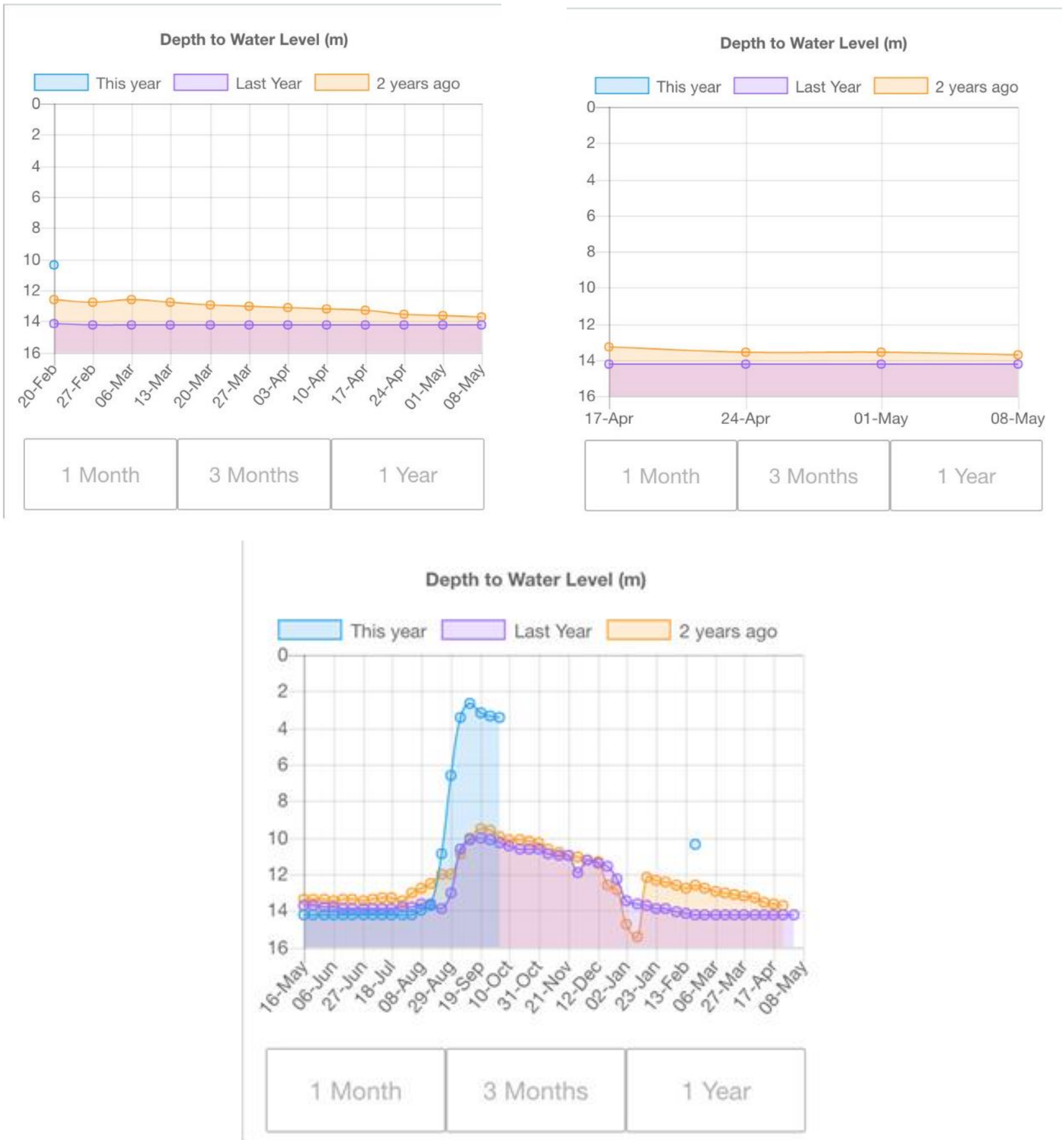

Figure 16. Example screen shots from MyWell app.

Finally, MyWell allows local MyWell facilitators to upload a large number of readings at a time. This allows an import of large amounts of historical data; increasing the immediate value of MyWell to the farmers.

In the next phase, MyWell will be scaled from 10 to 100 villages, and onto several orders of larger magnitude. This means making improvements to the features that make up the self-managed MyWell network. MyWell's analytics and visualisation features will be improved to allow for better groundwater visibility for farmers. This will also help cater to the science and research aspects of MyWell and MARVI as a whole.

The checking of data quality will be one of the new features to be developed in the next version. For example, for check dams and rain gauges, the reading can be backed up with a photo of the reading for future verification. Also, it may be possible to add a feature in the App to allow a government person to randomly check well reading and their data gets uploaded and plotted in a different colour.

As far as App features go, MyWell needs to learn a few new languages: Hindi, Gujarati, Punjabi, Marathi, Telgu, Kannad and Tamil. The SMS features of MyWell are targeted for improvement - with modern Chatbot and AI technologies. The goal is to make interacting with MyWell over SMS easier and more conversational.

7.13 Sustaining groundwater use – the magic of cooperation

7.13.1 Context

Sustainable use of groundwater has become critical in India, and it is a classic example of the tragedy of commons. Groundwater resource used jointly by many stakeholders and when there is no regulation or individual care, excessive use and depletion is a logical consequence. As with any other natural resource held in common, an aquifer tends to be viewed by individuals pursuing their own self-interests as a resource to be exploited before others are able to get to it. It is well known that unregulated use of a common resource, viz. groundwater, eventually brings ruin to all, since every farmer or other groundwater user is compelled to increase their individual benefit, without limit, from an aquifer system that has finite groundwater storage. Considering the inherent logic and tragedy of the commons, self-regulation appears to be the only way to avoid on-going tragedy of groundwater commons.

It is now increasingly being realised at different levels of government, funding agencies and stakeholders that any effective solution to the groundwater challenge requires technical, social, economic, policy and political inputs as well as a genuine participation from local communities and groundwater users. Access to groundwater for farming communities is also an emotional and complex issue as their livelihood and survival depends on it. Groundwater is also important for drinking water for both urban and rural communities in India.

In the MARVI project, we explored a suitable participatory approach and methodology with associated tools that will assist in improving supply and demand management of groundwater in the Meghraj watershed in Aravalli district, Gujarat, and the Dharta watershed in Udaipur district, Rajasthan, India. Based on series of meeting with farmer groups in the two watershed, we propose that Village Groundwater Co-operatives (VGC), following Ostrom's eight basic principles for managing commons, may be a way forward to deal with the current groundwater situation in India.

Since 2012, groundwater depth fluctuations and rainfall amounts have been monitored in all study villages in both watersheds. This has allowed farmers to correlate rainfall and recharge for their local situation. With their on-going engagement and exposure visits to Andhra Pradesh and Maharashtra (Figure 17), farmers have now come to a realisation that groundwater is not unlimited, contrary to their earlier belief that there is ‘underground river’ and drilling deeper can provide them with more water. The exposure visits have inspired farmers to go for some cooperative arrangement to manage their future use of groundwater. Some salient features of Andhra Pradesh and Maharashtra work are as under.

7.13.2 Malkaipeta Groundwater Cooperation (Telangana)

In Telangana (formerly Andhra Pradesh), farmer groups were empowered for managing groundwater use by monitoring rainfall, depth to watertable and groundwater pumping regularly throughout the year. This was achieved by a project named Andhra Pradesh Farmer Managed Groundwater Systems (APFAGMS). The data collected were then used by farmers to assess annual recharge, extraction and groundwater available for crop production. The information is then used by individual farmers to decide the type and area of crops to be grown in a given year based on water requirement of the selected crop(s) and groundwater balance available within the hydrological unit.

Inspired by the above project, a number of farmers in Malkaipeta village in Parigi block of Ranga Reddy District agreed to form a cooperative for improving the security of irrigation water supply. A group of farmers signed an agreement to share water according to the size of their land and not to drill new tubewells or drill deeper. Also, they all surrendered their existing dug and bore wells and agreed on which wells are suitable to meet their irrigation water needs. They all contributed an agreed amount per year to a central fund for maintenance of the pumping system. In addition to some selected existing wells, they also obtained government funding for two additional bore wells for their irrigation water needs. This way more water was made available to all farmers in the cooperative and their livelihood improved.

Figure 17. BJs being introduced to groundwater sharing and cooperation at Pargi, Telangana

7.13.3 Pani Panchayat

The concept of Pani Panchayat originated from Maharashtra and is the name first given to a movement by Mr. Vilasrao Salunke for motivating farmers of the Naigaon village of the drought-prone Purandhar taluka of Maharashtra in 1974. To deal with the drought situation, he negotiated a lease of 16 ha land with the village temple trust, constructed a recharge pond in the recharge area of the village and a dug well in the discharge zone. He then installed a pump and used this water to irrigate the land he leased. This inspired local farmers and got them interested in a scaling up of his experiment leading to the setting up of Gram Gaurav Pratisthan (GGP) through which the work was expanded to encompass both groundwater and surface water management. The idea of Pani Panchayat led to improved access to groundwater to all farmers in the area and substantial increase in their livelihood.

One of the significant outcomes of the MARVI project is the formation of pilot ‘Village Groundwater Co-operative’ (VGCs) in the two study watersheds. A series of village level meetings were held during the last ten months of the project to identify issues and challenges related to the sharing of groundwater among farmers (Figures 18 and 19). Based on these discussions, key principles for operationalising VGCs emerged and agreed by the interested groups of farmers. As result, three VGCs in the Dharta watershed and two in the Meghraj watershed have been formed and they are being formally registered.

Figure 18. Village level discussion to initiate groundwater sharing program at Hinta

Key points of agreement for VGCs

At present, there is a barter system in which farmer who provides groundwater to their neighbours receives one-third of produce in exchange of water provided to the neighbour. Farmers feel that the current barter system or the selling of water is not fair and it creates equity issues and does not support sustainability. A key principle that has brought farmers together for the VGC is that groundwater will be managed in such way through recharge activities and improving water productivity that no farmer will be worse off in terms of their net income after joining the cooperative. Further, once the cooperative is formed, no farmer member will deepen their well for an agreed time period and they will work together to increase recharge and reduce demand.

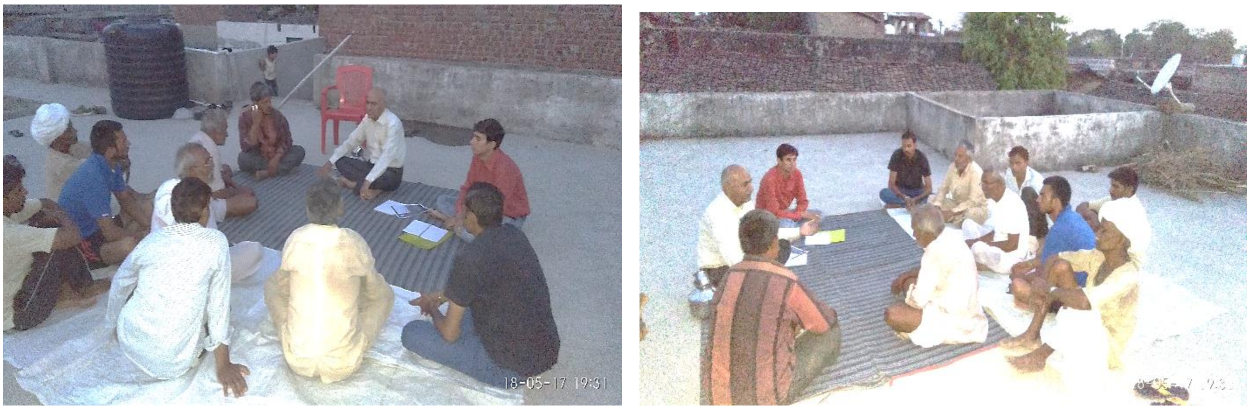

Figure 19. Village level discussion to initiate groundwater sharing program at Badgaon

8 Impacts

8.1 Scientific impacts – now and in 5 years

Key scientific impacts that have emerged out of the MARVI project are summarised below:

8.1.1 Bhujal Jankaar program

An outstanding new contribution through the Bhujal Jankaar (BJ) program has resulted in methodology for the assemblage of basic groundwater information at village level in a coordinated way at a density and frequency (weekly) of monitoring far greater than achievable through previous government programs. In particular, currently the Central Ground Water Board (CGWB) monitors only a handful of observation wells per block (each block is a few hundred villages) with groundwater levels measured at three monthly intervals. The methodology developed is cost-effective, highly engaging with local farmers and has resulted in scientifically valid data for understanding groundwater fluctuations and developing management decisions. The data collected by BJs has enabled better precision in evaluating groundwater storage changes between pre- and post-monsoon periods and during the Rabi season.

With continuous monitoring of both dug well and tube wells, it was possible to assess whether tube wells and shallow dug wells are in hydraulically connected aquifers. In each village of the Dharta catchment there is clear evidence of connection. This excludes any valid claim that drilling deeper wells would tap a separate aquifer and expand the water resource available to a village. Already this information has been disseminated in the Dharta watershed extinguishing deeper well construction, avoiding 'the tragedy of the commons'.

The data monitored by BJs have conclusively demonstrated the connectedness of water levels in all dug wells unequivocally proving to farmers that this is a single shared communal groundwater resource, and needs to be managed cooperatively. Also, the BJ data have resulted in a novel approach for future groundwater management strategies, in the absence of reliable well head elevations (a necessity for conventional groundwater modelling), to assess storage change during the Rabi combined with ET data in the Rabi, to estimate specific yield and hence the volume of aggregate recharge during the monsoon.

8.1.2 Check dam recharge estimation

In the MARVI project, we developed a simple daily water balance calculation to four check dams near Udaipur in southern Rajasthan where farmers took daily measurements of check dam water levels and rainfall for 2 years. The farmer measurements were proven to be highly reliable. The project resulted in a check dam recharge estimation method that is based on simple monitoring of daily water levels in check dams by BJs. There would still be a need for regional support (Government or NGO) in surveying impoundments and elevations and positions of observation wells, and in performing water balance calculations.

The methodology developed allowed assessment of the volume of recharge annually from observed check dams and assessment of runoff from catchments of check dams. The methodology also helped in the determination of proportion of rainfall running off, proportion of runoff detained by check dams, proportion of detained water recharged and evaporated. This then helped to estimate the volume and proportion of recharge via check dams and hence the proportion of agricultural livelihoods derived due to the installation of check dams in the area. Finally, this analysis resulted in the calculation of the benefit/cost ratio for check dam construction and for maintenance (scraping) of check dams, and the lateral extent of the impact of check dams on groundwater resources. The study also provided insight into how the two methods of removing deposited sediments in check dams, viz., mechanical method that used a bulldozer and hand labour, impacted on infiltration rate in storage area of check dams. In general, the mechanical scraping of check dams reduced the infiltration rate and negatively impacted on groundwater recharge.

Some specific results from the study revealed that the check dams augmented recharge by 33 mm in 2014, an “average” year, and by 17 mm in 2015, a “dry” year (where recharge is expressed as depth over the combined catchment area of the check dams). This corresponded to 2.0 and 1.0 times the combined capacity of these check dams in those years, and the average annual recharge volume, 743,000 m3, supports 16% of agricultural production in the rabi (winter) season from the surrounding villages. Total recharge was estimated to be 37% and 70% of combined runoff in 2014 and 2015, respectively. Mean dry weather infiltration rates averaged from the four sites over both years were 5–8 times the evaporation rate from check dams. Hence, based on farmer measurements, it is conclusive that the studied check dams are effective and efficient in recharging the local aquifer.

The results from the project demonstrates that a simple method can be used in future by farmers with basic training to determine the need for desilting of check dams in the following dry season and to provide essential data to allow quantification of recharge from check dams. This opens the possibility of scaling up, by orders of magnitude, the number of check dams that can be monitored and evaluated for their performance through engagement of BJs. With more check dams monitored over longer periods, quantitative data would become available to inform on sizing and placement of check dams in relation to local benefits, capital and maintenance costs and downstream impacts, and thereby to inform future investment in check dams.

8.1.3 Designing groundwater management policies

The absence of either state regulations or markets to coordinate the operation of individual wells has focussed attention on community level institutions for sustainable groundwater management. Socio-economic, cultural and attitudinal data collected in the study indicated that livelihood strategies, groundwater management and the propensity to cooperate are associated with the attitudinal orientations of well owners in the study watersheds. The research tested the hypothesis that attitudes to groundwater management and farming practices, household income and trust levels of assisting agencies were not consistent across the watersheds. This implies that a targeted approach, in contrast to default uniform programs, would assist communities craft rules to manage groundwater across multiple hydro-geological settings. The study revealed four statistically significant discrete clusters, supporting acceptance of the hypothesis. Further analyses revealed significant differences in farming practices, household wealth and willingness to adapt across the four groundwater management clusters. This mean there is a need to account for attitudinal diversity and associated framework while designing groundwater management policies and instruments in the future to sustainably manage local aquifers.

8.1.4 Groundwater and gender

The research on gender aspects in the two watersheds in Gujarat and Rajasthan is another area of scientific impact. The study reveals that although women are mostly considered to be domestic users of water while men are seen as the productive users, women make significant use of water for productive purposes as well. The results further confirm that women have to travel many times in a day to collect water for various uses. For drinking water collection alone, women have to travel an average of three times in a day which takes between 50 and 77 minutes depending on the season. It was inferred that if domestic water supply is improved, it not only saves women's time but also reduces the hard labour which could be used by women on livelihood activities that will increase their household income and improve wellbeing of families.

Also, the study of eight secondary schools located in two watersheds in Gujarat and Rajasthan to assess student perceptions about groundwater scarcity issues and the impact of the scarcity on their educational opportunities. School absenteeism was found to be linked with gender; female students missed schools more frequently than their male counterparts. School attendance records in Rajasthan showed that the frequency of female students missing school for 5 or more days per month was on an average 2-10 times greater than that for males. The gender difference in absenteeism in all schools was statistically significant. The study highlighted that groundwater scarcity in the study area, and consequent demand on the girls' time for household work including fetching drinking water are contributing factors towards limiting their educational and economic opportunities. Groundwater scarcity can be one of the key factors that could limit inclusiveness in the future and so the potential benefits of access to groundwater need to be considered in the empowerment of women.

8.1.5 Groundwater and community well-being

The examination of the relationship between groundwater institutions, management attitudes and subjective wellbeing of households has substantial potential to reveal initiatives that jointly improve aquifer sustainability and household wellbeing. Subjective wellbeing was calculated as an index of dissatisfaction (IDS), revealing ranked importance and the level of dissatisfaction of individual factors selected from economic, environmental and social/relational wellbeing dimensions. The analysis of data demonstrated that reliance on initiatives to improve household income alone is unlikely to result in improved individual subjective wellbeing for the study watersheds. This means, in future, it is important to design participatory processes at the village level by taking into account specific factors that are likely to jointly improve aquifer sustainability and household wellbeing.

8.1.6 Agronomic practices and groundwater sustainability

The results from field trials on the selection of crop varieties that have low water demand, the use of mulches to reduce soil evaporation and the application of vermicompost are expected to help local NGOs and state government agencies to implement water saving practices and will have scientific benefits at the national level in better understanding the issues and challenges of groundwater management in agricultural production systems. Also, they will assist in identifying opportunities of intervention to improve irrigation practices for higher water productivity and reduced water demand. In particular, the findings from the trials provide local data and recommendations for water saving through practices such as the use of straw and plastic mulch for conservation of soil moisture, water saving and improvement in farmer income through adoption of selected crop varieties. Also, the recommendation has some indirect sustainability benefits through the use of organic manures management, carbon sequestration and greenhouse gases reduction emissions in soils by preferential use of organic manures, vermicompost, green manure and inclusion of legumes in crop rotations.

8.2 Capacity impacts – now and in 5 years

The groundwater monitoring data and training have given farmers the key prime tool for groundwater demand management, use of the depth of water table at end of monsoon to enable Rabi planting area to be adapted to the volume of water available to complete the crop and meet drinking water needs. This facilitates groundwater management at local level, under governance measures yet to be adopted at state level under the GOI Water Resources Act 2013.

The action- reflection learning approach in the project is transferrable to other villages in over-drafted areas of Rajasthan and elsewhere in hard rock catchments of India where groundwater is an important source of irrigation supplies.

The project activities have continued to assist village communities, researchers from partner organisations, state government agencies and post-graduate students associated with the project to build their capacity in a number of areas. Some examples of capacity building in the project are listed below:

A total of four PhD students and seven master students from three university worked directly in this project:

MPUAT

PhD theses

(i) Yogita Dashora; submitted her PhD thesis in September 2017
(ii) Ragini Dashora; expected to submit her thesis in December 2018
(iii) Pratibha Katara; expected to submit her thesis in December 2018

Master theses

(i) Nikita Jain, completed in August 2013
(ii) M.B. Jayantibhai, completed in August 2014
(iii) Ravindra Singh, completed in August 2014

Western Sydney University

PhD theses

(i) Seema Dave; expected to submit her PhD thesis in June 2018

Master theses

(i) Michael Chew; submitted his Master thesis in November 2013

Carnegie Melon University, Adelaide

Master projects

(i) Lewis Daley, completed in August 2015
(ii) James Laney, completed in August 2015
(iii) Romin Parek, completed in August 2015

The above students were given significant guidance and assistance in terms of experimental design, data collection, analysis, modelling and the use of relevant software (e.g., SPSS). These students were assisted in their writing and presentation skills and are exposed to transdisciplinary approaches to improve the situation and make a difference to village communities who are struggling with groundwater scarcity. Further, the project also supported four undergraduate students from MPUAT for their final year project. Overall, the capacity developed of the undergraduate and post-graduate students through this project is significant and they will fill an important capacity gap in groundwater management in future government programs.

One of the capacity impacts of the project can be attributed to the publication of a book chapter in 2016 titled ‘Harnessing Community Capacity to Coordinate and Integrate Natural and Behavioural Science Perspectives: A Groundwater Management Case Study from Rural India’ in a book Developing Human Capacity in the Asia Pacific: Trends, Challenges and Prospects, Routledge.

In the first project workshop in Udaipur in February 2012, a total of 35 team members participated in ‘the Project Visioning’ workshop facilitated by Adj. Associate Professor Roger Packham. The aim of the workshop was to envision what will be achieved at the end of the project and five and ten years after the completion of the project. In the beginning of the workshop, many team members did not see the value of this exercise and just wanted to get on with the project task. However, at the end of the workshop and several years after the workshop valued what they learnt and the importance of understanding the purpose, planning and reflection in a transdisciplinary research project. Also, the workshop built the foundation of cooperation and team building which continued till now in the project and helped to create research approach that is systemic and consider people rather a technical understanding of the problem.

A number of trainings programs have been conducted by Arid Communities and Technologies (ACT) in the last the 12 months for early career researchers in the project on the use of GIS and for Bhujal Jankaars (BJs) on water management planning at the village level. The training has further equipped researchers and BJs in the analysis and interpretation of data being collected. This is now enabling researchers to develop GIS map layers and BJ's to help the village communities and the village level institutions (e.g., Sujal Samitee - Gujarati word for Water Cooperatives) to access local data and have a dialogue on the need to manage groundwater co-operatively.

The installation of rain gauges in the study areas has continued to build the capacity of villagers to understand the rainfall amounts and patterns and get some sense of the magnitude of rainfall. Further, SMS and smart phone based app, called MyWell, is helping BJs and other community member to report rainfall at a central server. This will help in wider availability of rainfall data to farmers. Overall, the practical experience in measuring weather parameters by BJs and sharing with village communities has helped in water literacy.

Demonstrations of high yielding, less water using hybrid crops, viz., maize, wheat, and mustard crops helped to demonstrate to farmers that using improved varieties of these crops has the potential to increase their net income within the water available when compared with the varieties they currently use.

8.3 Community impacts – now and in 5 years

The MARVI experience in the Meghraj and Dharta watersheds of Gujarat and Rajasthan has shown that villagers, when trained as Bhujal Jankaars (BJs - groundwater informed), can learn how to monitor, understand and take responsibility for collectively managing their groundwater. BJs are a cohort of farmers selected for specialised training to monitor and manage surface and groundwater coupled with enhanced skills to inform village level decisions. BJ training involved the measurement of watertable depth, rainfall amounts and check dam water levels and recharge rates. They became village champions of water conservation through mulching, irrigation management, contour bunding and the value of selecting high valued low water use crops. At completion of a rigorous training programme the BJs could also identify and mitigate polluted water and prioritise check dams for desilting. By combining their traditional knowledge with modern technologies, such as the MyWell mobile phone app, BJs are continuing to help their villages develop water security plans, adjust areas of crops in the Rabi season based on groundwater availability at the end of monsoon and widely share data and knowledge.

The participatory research in this ACIAR project has helped us to create shared learning among the community and it encouraged BJs to perform a decisive role to transmit the insights from the project research among the community. Further, BJs shared the various interventions of the ACIAR project in the local forums, including Sujal Samitees (Water Co-operatives), Farmer Clubs, Water User Groups, volunteers and the community leaders, and more importantly they sensitised the community on the groundwater issues, its impact on future of the community and possible strategies. Crop demonstrations have helped the community to use improved agricultural practices, particularly as they convinced many farmers in the study area to use vermicompost in their cropping.

Before the project interventions, the community did not explicitly relate groundwater recharge and depletion of groundwater due to pumping actions. Since BJs have developed a deeper understanding of the groundwater dynamics through weekly monitoring activities and training in geo-hydrological aspects, they are now able to explain to the community what is happening to groundwater scenarios in the study area with more credibility and making the community think and take action about their groundwater futures and solutions required.

The training of BJs for map preparation has been conducted by ACT, Bhuj. This training was divided into different modules as a step by step process to prepare maps related to land use and land cover, geology, water resources and geomorphology. This has increased the awareness about land formations above and below ground level and BJs now have a better understanding how the rock type, substrata, slope and land use relate to groundwater flow and availability. Further, the maps prepared by BJ are being used by Sujal Samitee members in the Meghraj watershed and so BJs are increasingly being recognised as valuable resource by these members.

There is anecdotal evidence as to how the ACIAR project has scientifically impacted the village communities in the two watersheds included in this study. The Meghraj watershed in Gujarat had widespread use of the surface irrigation method but in the last 3-4 years, there is a clear indication that more farmers have installed drip irrigation systems in the watershed and adopted crop varieties and agronomic practices that use less water. This change in farming practices is partly due to groundwater science literacy developed as result of the ACIAR project, particularly through community forums, field trial demonstrations, groundwater monitoring and the constant presence of project staff in the study area. In the Dharta watershed in Rajasthan, there is evidence that some farmers are changing their traditional crop such as wheat that require five to six irrigations to some medicinal crops, Isab Gol (*psyllium*) and Kaali Tulasi (*Ocimum sanctum Linn.*) that require only three irrigations. These are significant shifts in farming practices in the last 3-4 years, and this change is largely due to the ACIAR project. Further, this impact is likely to continue in the study areas and will spread to other area through the activities of the local partners and linkages developed with the government agencies.

8.3.1 Economic impacts

Improved irrigation and agronomic practices, including the use of the drip irrigation method, mulches, improved high yielding varieties, organic manures and Zn application has been promoted in the project areas of Rajasthan and Gujarat by conducting on-farm trials at farmers' fields to achieve water savings, improve crop yields and increase income of the farmers. These activities are expected to bring significant economic benefits to the farming community locally and in other parts of the two states.

Crop diversification by farmers in both the Dharta and Meghraj watersheds is occurring and the ACIAR project has partly helped in this change. The mass awareness in the Meghraj watershed has brought the groundwater scarcity issues to the forefront and influenced over 3,700 farmer families in 18 villages. There is some anecdotal evidence that farmers have started to explore and adopt crops and varieties that use less groundwater. For example, more farmers during Rabi season 2015-16 adopted the GW-11 variety of wheat in the Meghraj watershed and Isab Gol (psyllium) and Kaali Tulasi (Ocimum sanctum Linn.) in the Dharta watershed. The change in crop variety or crop type has resulted in a lesser number of irrigations and improved economic returns to farmers.

It is worth mentioning that 56 farmers from six villages in the Meghraj village have adopted the drip irrigation method on about 100 ha of land and they received about Rs 97 lacs in subsidy from the Government of Gujarat. The encouragement for the farmers to adopt drip irrigation was partly due to the community forums, creating awareness about the groundwater situation and field demonstration in the watershed through the ACIAR project. Similarly, through crop demonstration and field days in the Dharta watershed, farmers are now interested in replacing traditional crop types and varieties with crops and varieties that will increase their income and use less water.

8.3.2 Social impacts

Bhujal Jankaars in the Meghraj watershed have been meeting regularly with the farmer groups and are attending the Sujal Samitee to continue the dialogue on future water availability, the role of village groundwater cooperatives and options to secure water supplies. They used their weekly watertable data and the estimates of crop water requirements to explain the total water consumption in the area and illustrated the need to choose suitable crops so that they can match the water demand with water supply. This way they were able to draw the attention of the community towards demand management and the importance of groundwater recharge.

With the on-going presence of project staff and regular meetings with farmer groups, there is increased evidence that farmers now accept that groundwater is limited (previously many of them opined that there is an underground stream or the aquifer is connected to ocean) and the falling watertable is a village level issue and it needs to be tackled at the village level. The effort by individual farmers will not work and they are quite aware that deepening a well or installing a deeper tube well can affect the neighbour's access to groundwater. They feel helpless about their current groundwater situation but recognise that the solution needs to be developed and owned by the village or at least by a collective of farmers. The farming community in the two watersheds is now debating the concept of sharing groundwater through village groundwater cooperatives. The concept of water productivity (rather than crop productivity) is gaining momentum among the farmers. These are important outcomes from the ACIAR project in the two study areas and now gaining some recognition with the state government agencies.

In both study areas, farmers and other community members involved in field demonstrations, field days, training camps and other activities are from different socio-economic backgrounds. The project helped them to come together for action on a significant issue, i.e., over-pumping of groundwater, and assisting them to have a common understanding of groundwater and livelihood issues and possible ways to improve the situation. The warm welcome extended to the project team and participation by farmers, village communities, school teachers, students and local extension workers during community workshops was an indication of significant goodwill towards this project. Project partners developed strong interaction and collaboration with farmers and other stakeholders, and this will contribute further in strengthening the idea of research for development.

Farmers from neighbouring villages benefitted from field demonstrations in during three Kharif seasons, and the project has provided them a platform and an opportunity for sharing information and collaborative learning. This has also created a kind of solidarity among the farming communities to think about common issues such as groundwater, their livelihood and social upliftment.

As project teams in both the project sites involved farmers and other groups of all castes, rich and poor and men and women in demonstrations, field days, training and other activities of the project, this assisted in strengthening the ownership of groundwater issues and possible solutions at the village level. The project is also helping social cohesion among the local communities. Further, ACIAR project partners, particularly from Australia have developed a strong interaction and collaboration with project partners in India and postgraduate students at MPUAT.

8.3.3 Environmental impacts

Farmers and other people in the study area have started to develop the understanding of their water environment and one indicator of this is that they are now requesting project staff to access temperature, wind velocity, rainfall and humidity data recorded by weather stations in the study areas. With rainfall information displayed in villages on a daily basis, village communities are now thinking rainfall amount more in terms of quantity (mm) rather than qualitative terms they were earlier used to.

Some of our crop demonstrations and on-farm field trials were focused on the use of organic manures and reducing the use of inorganic chemical fertilisers in agricultural production systems. Farmers were also advised to grow pest resistant crop varieties and use pesticides based on target pests. These activities are expected to significantly contribute in reducing the water pollution and to a marked improvement in environmental protection by reducing the nitrite emission from the soils.

School engagement activities on a range of environmental topics such as water quality have increased awareness of students and teachers. The signs of enhanced awareness among students on a range of topics, including groundwater, are evident from their posters and drawings that students presented during the Poster Competition in Bhatkota School in the Meghraj watershed. The student presentations on the importance of water harvesting, drip irrigation, soil testing and climate change indicate that there is growing awareness among school communities about environmental issues.

Agronomic and water management demonstrations and water quality monitoring in the project created significant awareness among the farmers regarding environmental issues and the deterioration of water quality when they apply excessive amounts of fertilisers and pesticides. Further, farmers are now becoming increasingly aware of the fact that groundwater pumping needs to be limited and should not exceed recharges if they want to sustain their wells and tubewells.

8.4 Communication and dissemination activities

8.4.1 Project newsletter

To communicate project progress to farmers and other stakeholders in the study areas and beyond, project newsletter, called 'MARVI Manthan (a Hindi word meaning 'analysis') was developed. A total of four issues were published during the study, and they were widely distributed.

8.4.2 Project Factsheets

The following factsheets on key aspects of the project were developed as part of communication strategy within and outside India:

(i) MARVI Overview – explains about the project aim, approach, key components and main partners.
(ii) Bhujal Jankaar – explains about why we need participatory approach, the concept of Bhujal Jankaar, their role and the training program.
(iii) MyWell App – explains why we need an app, how it works, what it can do and some example outputs.

8.4.3 MARVI web site

The web site, www.marvi.org.in , has been developed and launched for public access. The purpose of this website is to introduce the project and its approach, list who is involved in the project, explain the key achievements and make the various project outputs available for wider use. The web site will provide opportunity to individuals and groups working in topic area similar to that of MARVI to contact the project partners for future collaboration and networking. This will also help in keeping the various partners connected and extend the MARVI work and its impact into the future.

8.4.4 International Workshop

The MARVI project team was co-organiser of an international workshop sponsored by ACIAR. The workshop was titled 'Water Security and Groundwater Management for the Agriculture in the Age of Climate Change' and held during February 3-5, 2015 at TERI

Complex New Delhi, India. There were nine presentations from the MARVI project and it provided a valuable opportunity to share the project work with participants at the national level.

8.4.5 National Workshop

The National Workshop titled 'Groundwater Monitoring, Planning, Recharge and Sustainable Use: Village Level Participatory Approaches and Tools' during May 30-31, 2017 in Ahmedabad, India was effective in engaging key stakeholders and disseminating project findings. The workshop was attended by over 120 policy makers, researchers, planners, government officials, NGOs, private sector specialists, farmers and community groups. It helped to facilitate an active, vigorous and open dialogue to discover ways to strengthen the institutional capacity and frameworks for effective village-scale groundwater management. The workshop also helped to share lessons from the MARVI project and provided hands-on experience / demonstration of field tested MARVI tools, including MyWell app, and methodologies to effectively implement MAR works, assist communities craft both cooperative strategies and village level demand management.

8.4.6 Conference presentations

1. Sustainable Groundwater Management and Conservation Agriculture in Rajasthan, India. 6th World Congress on Conservation Agriculture, 22-25 June 2014, Winnipeg, Manitoba, Canada.
2. Managed Aquifer Recharge through Village-level Intervention in Rajasthan and Gujarat. In Proc. the South Asia Groundwater Forum, 1-3 June 2016, Jaipur, India.
3. Participatory Groundwater Management at Village Level in India – Empowering Communities with Science for Effective Decision Making. Australian Groundwater Conference 2015, 3-5 November 2015, Canberra.
4. Performance Evaluation of Groundwater Recharge Structures: An Application of Water Balance Analysis. Sixth International Groundwater Conference, IGWC 2015, 9-11 December 2015, SRM University, Chennai, Tamil Nadu, India.
5. Participatory Groundwater Monitoring – The Role of BJs, Indian Society of Agricultural Engineers Annual Convention, 19-21 January 2016, CAET, Bhubaneswar, India.
6. Understanding Groundwater Recharge Dynamics of 2 Anicuts in Hard Rock Areas in Rajasthan, India, ISMAR9 symposium, 20-24 June 2016. Topic No: M9 - MAR in developing countries, México City, Mexico.
7. Managed Aquifer Recharge: A Significant Approach for Sustainable Agriculture. International Conference on Eco-Friendly and Socially Responsive Economy and Equity: Issues and Challenges of 21st Century for emergent Sustainable Development Amongst SAARC Countries, 9-11 January 2017, MLS University, Udaipur, India.
8. Quantifying recharge from ephemeral stream check dams in a hard rock area with sparse data. Australian Groundwater Conference, 11-13 July, 2017, the University of New South Wales, Sydney.
9. Economics of recharge through check dams in a hard rock area of Rajasthan, India. 44th Annual Congress "Groundwater Heritage and Sustainability" Dubrovnik, Croatia, 25 - 29 September 2017.
10. Addressing the Tragedy of Groundwater Commons: Understanding the Challenge and Developing a Framework for Village Groundwater Co-operatives. XVI Biennial IASC Conference 'Practicing the commons: self-governance, cooperation, and institutional change', to be held from 10 - 14 July 2017, Utrecht, The Netherlands.

8.4.7 Public seminars

1. Hard Rock Groundwater Recharge Using Check Dams in Rajasthan, India and its Relevance to South Australia, Goyder Forum, Adelaide, 3-4 July.

8.4.8 Radio talk

1. Groundwater issues and challenges – the role of participatory management, Kheti and Ghar (Farming and Home) Program, 6.30 pm, 10 minutes, All India Radio, Udaipur, 18 February 2015.

8.4.9 Television

1. The National Workshop during May 30-31, 2017 was covered in the main evening news with interview of MARVI team member by ETV channel (State level).

8.4.10 Webinars

1. Managed Aquifer Recharge thru Village-level Interventions – MARVI. Webinar: ICE-WaRM, Adelaide, 4th May 2017.
2. Hard rock Groundwater recharge using check-dams. Webinar: ICE-WaRM, Adelaide, 15 June 2017.

9 Conclusions and recommendations

9.1 Conclusions

Based on the MARVI experience, villagers have shown that with sufficient resources and guidance they are capable of and are willing to measure and understand their groundwater and equip themselves to self-manage their groundwater future. Villagers can do what government has not been able to do directly. State and Central Governments are increasingly alert to their new role in supporting participatory groundwater management and ensuring communities have the skills and knowledge needed to be effective in democratising the management of groundwater in rural India.

The water balance methodology developed in the project can be used by farmers to determine the changes in infiltration trends and thus the need for desilting of check dams in the following dry season and to provide essential data to allow quantification of recharge from check dams. The methodology developed in this study is cost-effective, reliable and engages farmers and helps in monitoring more check dams over longer periods.

The study indicated that greater effectiveness can be achieved if rules and strategies to reduce over-extraction of groundwater are based on approaches that are tailored to individual village communities rather ‘one size fits all’. In particular, individual attitudes about aquifer connectivity, willingness to amend well operations, water conservation and time orientations vary across villages and watersheds. Importantly understanding the structure and distribution of attitudinal diversity means programs can be tailored to match village attitudes.

A detailed socio-economic study in the MARVI project helped in understanding the needs and aspirations of villagers leading to a shared and plausible vision of what is possible to improve their livelihoods and those of their children. The future visions reveal a palette of home grown solutions articulated, endorsed and supported by the community, including a ban on drilling new tube wells, and consideration of village level groundwater cooperatives.

The project has demonstrated that engaging villagers for field monitoring and empowering them through capacity building is an effective strategy to engage them in a dialogue and motivate them for action. This has resulted in the formation of ‘Village Groundwater Co-operative’ (VGCs) for sharing groundwater in the two study watersheds.

Overall, a key to groundwater management is the imperative of whole of aquifer governance. Some aquifers underlie many villages or districts and everyone will need to cooperate to secure their water future. Understanding the aquifer capacity and limits is necessary. Foregoing short term self-interest and the adoption of longer term cooperative approaches at multiple levels will be necessary to sustain the aquifer and all dependent communities. Novel mechanisms will be needed to enable cooperation over large distances; democratising the management of groundwater in rural India. The village level options and capacities revealed during the MARVI programme represent a logical and coherent foundation to assist other groundwater communities in India faced with similar groundwater stresses.

9.2 Recommendations

9.2.1 State and Central Governments

- Need for ongoing support, e.g., transitional support from ACIAR to Rajasthan and Gujarat Governments for the next 5 years to prototype the support given to these communities. Propose: Working with state and district administration (and Central Government) to:

- Develop protocols and institutions to support ongoing BJ activities, e.g., as an NREGA function, but carried out throughout the year for weekly monitoring and daily monitoring of check dams whenever they are wet.
- Assist communities to learn from their experiences re crop areas and successful completions in relation to groundwater levels (every well may differ).
- Undertake reviews, say each 5 years, to demonstrate satisfactory water sharing arrangements that meet local, state and national needs. Reporting on rain gauge data, evaporation data, groundwater levels, effectiveness of groundwater demand management and recharge enhancement and institutional arrangements, communications and sustainability of systems.
- Perform level surveys and mark well heads to enable future upgrading into groundwater models. This will be particularly important with multiple levels of sub-catchments within a catchment and ultimately allow formation of catchment water management entities with representation at the sub catchment level.
- Make use of the existing MARVI catchments and BJs' experiences with the training of BJs for other catchments under the GOI plan for 19,000 BJs in the current 5-year plan.
- Develop capabilities for technical support for BJ programs, including managing a mobile phone web-based data system, error checking and quality assurance, surveys of check dams to produce area and volume-elevation curves) and well head elevations, installation of gauge boards, maintenance programs for monitoring equipment and for scraping of check dams, and ultimately in modelling where required, and in reviewing performance of check dams and sand filters and dug wells used for recharge and in locating sites of new check dams where warranted.

- Government and communities need to ensure the formation of surface and groundwater management plans to embrace the principles of procedural fairness and distributional equity from village to whole of catchment levels. The voices and active participation of women are critical to success as are those of the most vulnerable and disadvantaged communities. All relevant options to address groundwater security, surface water flow requirements and water quality protection require careful and thoughtful deliberation. The convergence and recognition of the value of both indigenous knowledge and scientific knowledge is a vital ingredient in an expanded suite of groundwater options.
- Governments need to set or revise policies on water management, watershed management, water supply and sanitation, agriculture, rural development, energy and pollution control that are consistent with aquifer scale groundwater management. We need to actively support and facilitate capacity building, institutional development and participation and cooperation among all stakeholders.

9.2.2 Bhujal Jankaar Program

Investment is needed in selecting, training and accrediting BJs at village level and their facilitators at local, state or national level. Action is needed to support BJs through qualified, locally based facilitators to collect reliable, verified measurements that will enable the formation of empirically based, village-level groundwater management plans, including supply and demand-side measures leading towards self-reliance.

9.2.3 Out-scaling of the MARVI approach

To support implementation of the MARVI approach in other areas, community awareness must be raised through media of all types, school and community resource books and photovoice books. Also, we need to make readily available the necessary technical publications in all required languages. We need to promote the use of groundwater monitoring tools, including the “My well” mobile phone app, watertable depth measurement kits, water quality probes and gauge board templates for check dam water level measurements. These tools that align with village technical capacities allow both a rapid increase in the monitoring of rainfall, wells and recharge structures at village level. Collated groundwater data will be reported online and will be accessible for use in advancing water security plans.

Efforts need to be made to develop an inventory of all recharge structures at the state and national level. Existing recharge structures require sustained monitoring to further refine siting and the design of new MAR structures, improve cost effectiveness of silt removal, and quantify the economic impacts of these investments in recharge enhancement alongside demand-side measures. Based on the MARVI experience and some further work, Excel™ based tools can be developed to estimate groundwater recharge volumes at the end of the monsoon and assess the performance of recharge structures using data from monitoring rainfall and check dams.

Each village can be different from the point of view of groundwater management and therefore groundwater management actions should be based on the diversity of socio-economic attributes. A singular reliance on a uniform, ‘one size fits all’, approach will not help in the effective management of groundwater or achieve high returns from public investments for groundwater projects.

9.2.4 Need for a broader groundwater management approach

The work in the MARVI project has strengthened the view that groundwater management actions need to be trans-disciplinary, trans-departmental, trans-ministry and holistic to achieve long lasting village water security. Also, groundwater management needs to start from the village level and evidence from MARVI indicates effective groundwater cooperation and sustainable water sharing can be attained at the village and aquifer level. Further, urban and peri-urban areas are significant users of groundwater and rain water harvesting and recharge actions can be readily implemented in urban areas to reduce the stress on village groundwater resources.

9.2.5 Specific Actions

Groundwater Literacy and Community Capacity Building

- Create mass awareness on groundwater management through television, radio, newspaper and other means.
- Make significant investments to build the capacity of the community, particularly groundwater literacy that will dispel myths about groundwater availability and flow. Further, ensure that groundwater literacy is prominent in schools and communities to create local groundwater champions. A user friendly and well-illustrated book, ‘*Our Groundwater – A Resource Book*’ is available in English, Hindi and Gujarati.
- Implement programs to develop community-led village water security plans using rainfall, groundwater levels, check dam and water quality data monitored by villagers themselves.
- Make groundwater quality and quantity management a part of main stream education.
- Declare 2018 ‘*The National Year of Groundwater’*.

BJs (Bhujal Jankaars)

- Build the capacity of BJs to provide reliable and validated local water data to develop village water security plans. Resources for BJ training have been developed and fine-tuned to suit local conditions.
- Formally connect BJs with Gram Panchayats and facilitate BJs' involvement in any groundwater and other natural resources management schemes of the government implemented by Gram Panchayats.
- Recognise the collection of reliable watertable, rainfall, check dam water levels and water quality data by BJs and make them widely and easily available.
- Facilitate BJs to play a significant role in the implementation of the 'five waters' concept that involves integrated management of rainwater, surface water, groundwater, soil water and wastewater.
- Establish a 'National BJ Institute' that is coordinated by organisations such as Arid Community and Technology (ACT) with virtual BJ Institutes established in other states to assist in 1) the training of BJs and 2) their on-going involvement and capacity building in village groundwater management.
- There is also a need to extend the BJ concept to urban areas (Urban BJs) to help with urban groundwater recharge and management. This is because any water scarcity in urban areas can lead to the importation of groundwater by urban dwellers from nearby peri-urban and rural areas through water tankers and other means and thus reducing the groundwater availability for agriculture.

Integration, Institutional and Policy Actions

- Integrate demand management with current programs such PMKSY (Prime Minister's Agricultural Irrigation Scheme) and MGNREGA schemes at the national level.
- Secure water rights and associated responsibilities and obligations need urgent clarification. Groundwater is a common pool resource accessed by multiple users and stakeholders at the village and aquifer levels.
- State and Central Government policies need to be designed and evaluated for sustainability of surface water and groundwater resources.
- Develop an inventory of recharge structures and monitor them for their performance and desilting.
- Initiate a crowdsourcing program to measure rainfall in every village of India via farmers (citizen scientists) and collect the data through using the MyWell app that can work with smart phones with internet connection or with an ordinary mobile phone by sending data through an SMS. The one-off investment required for doing this will be less than Rs 250 per village with little on-going costs.
- Cropping patterns should follow the patterns of groundwater and surface water availability in any given year. Further, farmers need to be given incentives to grow crops that have higher water productivity and therefore policy incentives need to be designed appropriately.
- Stringent measures are required to restrict the discharge of polluted water that can infiltrate aquifers.
- Consider providing tax incentives or economic instruments for activities that support groundwater recharge and management.

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10.2 List of publications produced by project

10.2.1 Reports/Resource materials/Books/Video documentary

1. Kookana, R.S., Maheshwari, B., Dillon P., Purohit, R. and Oza, S., 2017. Our Groundwater – A Resource Book. ACIAR, Canberra, Australia; www.marvi.org.in , ISBN 978-1-74108-439-9, 81p.
2. Chew, M., Maheshwari, B., Purohit, R., Dillon, P., Oza, S., Bohra, H., Dashora, Y., Jadeja, Y., Kookana, R., Packham, R., Ward, J. and Katara, P., 2017. Groundwater Stories – Villagers Share their Voices. Western Sydney University, Penrith, NSW 2751, Australia, 60p, ISBN 978-1-74108-441-2
3. Jadeja, Y., Maheshwari B., Thaker, B., Goradiya, V., Kumbharana V., Tiwari, K., Packham, R., Oza, Sachin, Purohit, R., Hakimuddin, 2017. Understanding Geo-hydrology – A Resource Book for Bhujal Jankaar. www.marvi.org.in 45p.
4. Groundwater – the way forward (A video documentary with interviews of farmers, researchers, policy makers; completion expected in February 2017).

10.2.2 Book chapters

1. Maheshwari, B., Ward, J., Varua, M.E., Purohit, R.C., Hakimuddin, Oza, S., Y. Jadeja, Y., R. Packham, R., 2016. Harnessing community capacity to coordinate and integrate natural and behavioural science perspectives: a groundwater management case study from rural India. In: M. F. Rola-Rubzen and J. Burgess (ed.), Developing Human Capacity in the Asia Pacific: Trends, Challenges and Prospects, Routledge, London, p200-216. ISBN 978-1-138-84370-7.
2. Varua M., Ward J., and Maheshwari, B., 2016, Understanding farmers' groundwater attitudes for better groundwater management in Sustainable Development. Vol. 1, Brebbia, C. A., U.K., pp 477-487.

10.2.3 Refereed journal articles

1. Dashora Y., Dillon P., Maheshwari B., Soni P., Dashora R., Davande S., Purohit R. C. and Mittal H. K., 2017. A simple method using farmers' measurements applied to estimate check dam recharge in Rajasthan, India. Sustainable Water Resources Management, (in press), DOI: 10.1007/s40899-017-0185-5
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10.2.4 Journal articles under review

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3. Chinnasamy, P., Maheshwari, B. and Prathapar, S., 2017. Adaptation of Standardised Precipitation Index for Understanding Water Table Fluctuations and Groundwater Resilience in Hardrock Areas of India. Environmental Earth Sciences (under review)
4. Varua, M., Ward, J., Maheshwari, B., Dave, S. and Kookana, R., 2017. Groundwater Management and Gender Inequalities: The Case of Two Watersheds in Rural India. Groundwater for Sustainable Development (under review).
5. Shah, T. and Maheshwari, B., 2017. Community Based Groundwater Recharge Movement in Gujarat, India: Understanding its Impacts on Groundwater Availability. Groundwater for Sustainable Development (under review).

10.2.5 Conference presentations/webinars

1. R. C. Purohit, Basant Maheshwari, Yogita Dashora, Pratibha Katara, Hakimuddin, P K Singh, H K Mittal and Prahlad Soni, 2014. Sustainable Groundwater Management and Conservation Agriculture in Rajasthan, India. 6th World Congress on Conservation Agriculture, 22-25 June, Winnipeg, Manitoba, Canada.
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11 Appendixes

11.1 Appendix 1:

The various documents, videos, photo albums and newspaper clips are available on www.marvi.org.in .