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Farm level rainwater harvesting across different agro climatic regions of India: Assessing performance and its determinants

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ABSTRACT

Rainwater harvesting and its utilization have a very important role to play in harnessing the production potential within dryland systems. This study assesses the performance of small rainwater harvesting structures (farm-ponds) in 5 major rainfed states of India over the period 2009–2011 using data from multiple sources and stakeholders. Rainwater which is harvested using structures of varying types and sizes was used for either supplemental irrigation or recharging open-wells. In many cases, the farm level rainwater harvesting structures were highly effective for rainfed farming and had a multiplier effect on farm income. In some situations however, it was viewed by farmers as a waste of productive land. The use of farm ponds in Maharashtra, for example, resulted in a significant increase in farm productivity (12–72%), cropping intensity and consequently farm income. In the Chittoor district of Andhra Pradesh, farm pond water was profitably used for supplemental irrigation to mango plantations, vegetables or other crops and animal enterprises with net returns estimated to be between US$ 120 and 320 structure^{-1} annum^{-1}. Despite such examples, the adoption of the farm ponds was low, except in Maharashtra. A functional analysis of the reasons for high adoption of water harvesting structures indicated that factors such as technical support, customized design, level of farmer participation, age, existing ownership of open wells, annual rainfall and household assets were the major determinants of performance of farm-level rainwater harvesting structures. Based on this countrywide analysis, different policy and institutional options are proposed for promoting farm-level rainwater-harvesting for dryland agriculture.

1. Introduction

In the rainfed arable systems of India which account for about 55% of the total sown area (Shankar, 2011), capturing and efficiently using rainfall is the most critical component for profitable and resilient rainfed systems. The successful production of rainfed crops largely depends on how efficiently soil moisture is conserved *in situ* or by harvesting the surplus runoff and recycling it for supplemental irrigation. Recycling of waste water is the another potential source to tap for rainfed regions but needs greater investment, sensitization of stakeholders and capacity to ensure safe to use standards for recycled wastewater (Regli et al., 1991; Shuval et al., 1997; Lopez et al., 2006). The Comprehensive Assessment of Water Management in Agriculture (CA, 2007) describes a large untapped potential for upgrading rainfed agriculture and calls for increased water investments in the sector. Over the recent decades, interventions around rainwater harvesting have been an important component of rural and agricultural development programmes in India. The importance of rainwater harvesting for agriculture is now more urgent with increased climatic variability and higher frequency of extreme weather events (Rao et al., 2009; IPCC, 2014). High rainfall variability (AICRPDA, 1991-2011) in the selected seven study districts further makes an important case for rainwater harvesting for agriculture. Research institutions have worked on designing efficient rainwater harvesting structures for different rainfall regions and soil types, effective storage of harvested water and methods for its efficient use in the Indian context (Kumar et al., 2011; Reddy et al., 2012). According to Sharma (2009), many more community managed rainwater harvesting initiatives have resulted in failure than success with most programmes fail-

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ing to include effective strategies for maintaining the communal water harvesting structures beyond the project life (Shah, 2007). Despite its obvious potentials, many communities fail to overcome collective action challenges in sustaining the ecosystem services over time (Joshi et al., 2005; Falk et al., 2012). Individual control over available water enables farmers to better plan agricultural operations; use water resources more efficiently and productively, and maintain structures for long term use (Takeshima et al., 2010; Molle et al., 2003). The community based initiatives have their own limitations which are usually related to institutional failure (Shah, 2007). This has led to government's increased investment priority for promoting rainwater harvesting at the farm level (Govt. of India, 2007). However, despite of the technical potential of these technologies, the adoption and performance these efforts have "*...not been very satisfactory especially in enhancing agricultural productivity and farm income*" (Rao et al., 2009). There in need to generate more information on economic viability of farm level rainwater harvesting, factors influencing its performance and implementation under different agro-ecologies would be helpful in guiding the future investments. The study presented in this paper makes a comprehensive assessment of performance of rainwater harvesting at the farm level in five major rainfed states of India representing semi-arid and arid regions to better understand the drivers and conditions under which previous initiatives have been successful or which factors led to failure.

2. Materials and methods

2.1. Data

The study uses data from various sources including a survey and focus group discussions (Table 1) to assess the performance of farm level rainwater harvesting under different agro-climatic conditions in semi-arid and arid regions in India. The surveys were undertaken in single districts of five major rainfed states (Districts) namely; Andhra Pradesh (Chittoor), Maharashtra (Akola), Karnataka (Bangalore rural), Tamil Nadu (Vellore) and Rajasthan (Bhilwara) with reasonable density of farm ponds, all representing semi-arid agro-ecologies. Two more districts, Jodhpur from Rajasthan and Anantapur from Andhra Pradesh (AP) were also included in the study to represent major hot arid agro-ecologies in India. This selection used advice from national scientists of Dryland project of Central Research Institute of Dryland Agriculture (CRIDA) as well as the published sources (Rao et al., 2009). In the selected districts annual rainfall varied from 327 to 949 mm and has diverse soil types (Table 4). In the randomly selected clusters of 3–4 villages from each district (Fig. 1) a rapid rural appraisal was undertaken covering about 100 households selected randomly from each cluster. It revealed that a very low proportion of farmers (<10%) possessed rainwater harvesting structures (RWHS) for agricultural purposes. From this sample of farmers with and without RWHS, 2 groups of 20 farm households/district were randomly selected. Thus the study sample of n = 200 farm households (HHs) represented a wide range of rainfall, soil and cropping systems. The data were collected for the year 2010–2011 through interviews using structured questionnaire administered in June–July 2011. Although construction of RWHS was partially funded by various government programmes, structures were largely constructed and maintained by farmers. The data were collected on socio-economic profile of the households, characteristics and utility of RWHS and initial investment and operational cost of RWHS, adoption and awareness levels of farmers' about rainwater harvesting techniques and benefits, for example, increased cropped area and productivity, increased income due to diversification to high value enterprises. We also collected information through structured discussions with programme implementing agencies (district water development agency in Andhra Pradesh, agriculture and soil & water conservation departments in other states), research scientists from CRIDA and Agricultural Universities in respective states, relevant non-governmental organizations (NGOs): Foundation for ecological security (FES) in Rajasthan and AP; DHAN foundation in AP and Tamil Nadu, local panchayats, policy makers (Director watershed programmes)as well as on-site observations.

To further assess the impact of rainwater harvesting on agricultural productivity and farm income, a second data set was collected from projects undertaken by a federally agricultural research funded agency, the Central Research Institute for Dryland Agriculture (CRIDA). Data from a network of on-farm trials conducted by CRIDA and collaborating agricultural universities' scientists in different regions of India representing diverse agro-climatic situations (rainfall 500 to >1000 mm), soils (Aridisols, Alfisols, Vertisols, Inceptisols, Antisols, Oxisols) and cropping systems. Some common characteristics of the rainwater harvesting structures include: structurally farms ponds are not covered structures, except in Jodhpur (arid Rajasthan), where RWHS was much smaller in size and covered to avoid high evaporation losses during hot times (Seethapathi et al., 2008). In Jodhpur, the rainwater was harvested in an underground cistern made of concrete and locally known as Tanka (Goyal and Issac, 2009). The rainwater harvested and stored through farm ponds on individual fields was recycled mainly for supplemental irrigation during dry spells in the growing season. In some villages in Tamil Nadu and Andhra Pradesh these structures were dug in the vicinity of open wells (most of these open wells dried up earlier) and were used as percolation ponds for their recharging. All the sample households were rainfed and did not have access to underground water through bore-wells except around 20% households in Anantapur and Vellore who had owned shallow open wells. These open well owning households accounts only for 6% of the total sample households. For the open well owning households, the benefits were calculated as additional area irrigated because of recharging of the open wells. We assessed the impact of farm level rainwater harvesting on cropping pattern, cropping intensity, diversification to high value crops, crop and livestock productivity, net returns and perception of farmers to risk.

2.2. Data analysis

The farmers' contribution to the initial investment on RWHSs was about 50%, but the benefit-cost analysis was carried out for both the scenarios; scenario I. considering total cost (farmers contribution + government contribution), which included the fixed costs (depreciation, interest, opportunity cost of land (lease cost) where structure is constructed) and variable costs such as annual maintenance cost at the rate of 2% of capital cost (Palmer et al., 1982) and operational expenditure such as labour, pump hire charge and diesel cost for irrigation. For those households who had access to pump sets, the hire charges of 3 hp diesel pump set using plastic pipe or sprinkler as delivery systems were included in the cost. Such hire charges for pump set varied from US$ 8 to US$ 10 per day. A few farmers in Chittoor district also used a traditional device to lift pond water manually engaging two persons and accordingly the cost was accounted. Scenario II, where 50% government support for initial investment was not included in benefit cost analysis, wherein the analysis considered all costs but only 50% of the fixed cost in terms of depreciation and interest on initial investment. The internal rates of return (IRR) were estimated to reflect long term performance of RWHS following Gittinger (1982) and assuming 15 year life of farm ponds (Reddy et al., 2012; Malik et al., 2013). The annual net current benefits due to farm pond were calculated for each farmer and then mean for each district. However the IRR was

Table 1
Multiple sources of data, its coverage and purpose.

Source of data	Coverage	Purpose
• Participatory on-farm trials on farm level rainwater harvesting	• Major rainfed regions in India (10 centers of Dryland project)	• Validation on impact of farm level rainwater harvesting by analysing participatory on-farm trials
• Rapid rural appraisal (RRA)	• Seven clusters of villages in five selected states	• Identifying farmers with RWHS for sampling
• Farmers survey	• 200 households from seven clusters of villages in five selected states	• Studying benefits and conditions for adoption of farm level rainwater harvesting
• Focussed group discussions (FGDs) with farmers	• Seven clusters of villages in five states	• Identifying determinants influencing adoption and performance of RWHS
• FGDs/workshop with scientists, project implementing agencies and mid-policy actors	• Five selected states	• Understanding technical aspects and implementation strategy and related constraints and opportunities
• Field observation	• Seven clusters of villages	• Validation of information on location, design and utility of RWHS by the multidisciplinary team

estimated using the average initial investment, cost and returns for a district.

The total area irrigated using the harvested rainwater or recharged open well was considered as the key measure of performance of the RWHS and was used as dependent variable in the multiple linear regression analysis. To study the determinants of performance of RWHS, multiple linear regression function was fitted. The explanatory variables for regression analysis were identified based on the stakeholder consultation and focus group discussions (FGDs) with the farmers. These factors included landholding size, age and education of household head, household assets, and annual rainfall and the composite variables such as social networking, level of farmer participation, provision of rainwater harvesting as a component or a package and level of technical support in the initial stage. Each of the composite variables was measured by constructing an index on the scale of 0–10. A total of five indicators were identified for each composite variable with a maximum score for each indicator as 2 and thus 10 for a variable (Table 2). Indices score for each of the composite variable for each farmer was calculated based on the presence of the different indicators (five) for the relevant farmer. These composite variables (indices) were included in linear regression analysis to understand the magnitude of their influence on the performance of RWHS. To ascertain the relationship between farmers' age and adoption of the technology, originally we have included age of the household (HH) head as an explanatory variable. But to specifically examine as to which age groups are most likely to adopt the technology, we have constructed an index wherein ages below the median (45) were given the score of 2. Remaining observations were given the score of 1. Then the age category variable was regressed in place of Age of HH head.

The test of assumptions of the ordinary least square for multicollinearity, heteroscedasticity and normality did found the model valid (Appendix). Regression coefficients depend on the underlying scale of measurements. In an attempt to solve the issue of units of measurement, the coefficients are standardised. This is done by standardising the variances of the dependent and independent variables to equal 1 (Appendix). The relationship between area irrigated using harvested water and most significant explanatory variables was further illustrated by using trends.

3. Results and discussion

In the dryland regions, it is well known that poor rainfall distribution leads to dry periods that often decrease yield potential (HarvestChoice, 2010). While there are many opportunities for management to increase water use efficiency (WUE) via a range of agronomic management practices in broadacre systems (Kirkegaard et al., 2014a) including rotations (Whitbread et al., 2015), tillage systems and residue management (Kirkegaard et al., 2014b; Thierfelder and Wall, 2009), in the Indian context small farm size limits the impacts of such interventions. Therefore the storage and later reuse of rainfall via irrigation represent a widely promoted intensification strategy in India (Keller et al., 2000; Reddy et al., 2012; Malik et al., 2013). In this paper, we present and discuss the impact of public programmes which have implemented farm level rainwater harvesting schemes across 5 states.

3.1. Participatory on-farm trials on rainwater harvesting

The analysis of participatory on-farm trials on farm-level rainwater harvesting across different rainfed areas in India, rainfall gradients (500 to >1000 mm per annum) and cropping systems indicate the potential benefits (Table 3). The size of the RWHS varied from 250 to 2500 m^3 depending on the runoff potential and farmer preference. The initial investment on the construction of a small farm pond or other RWHS varied from US$ 838–2214 and was equally shared by the farmers and the project. The net returns generated were economically viable, ranging from US$72 to $381 $annum^{-1}$ $structure^{-1}$ depending on region, rainfall, soils, cropping systems and pond size (Table 3). The internal rate of return (IRR) was higher than the interest rate for the majority of the households, but the returns were much higher in the regions where vertisols were common and annual rainfall was >750 mm. These results support increased public investment on farm-level rainwater harvesting for enhancing production capacity of rainfed agriculture (Malik et al., 2013). These RWHS were constructed under the supervision of scientists, and farmers had access to technical support at village level during the project period. But the performance and impact of the RWHS constructed and managed by farmers with support from various government programmes had shown the mixed results as analysed and presented in the next section.

3.2. Farmers managed farm level rainwater harvesting

This section analyses the performance of farmers' managed rainwater harvesting structures in five states covered under this study. These RWHS were constructed by farmers with funding support from various public schemes such as Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGS), Integrated Watershed Management Programme (IWMP), National Agricultural Development Programme (RKVY) and National Hor-

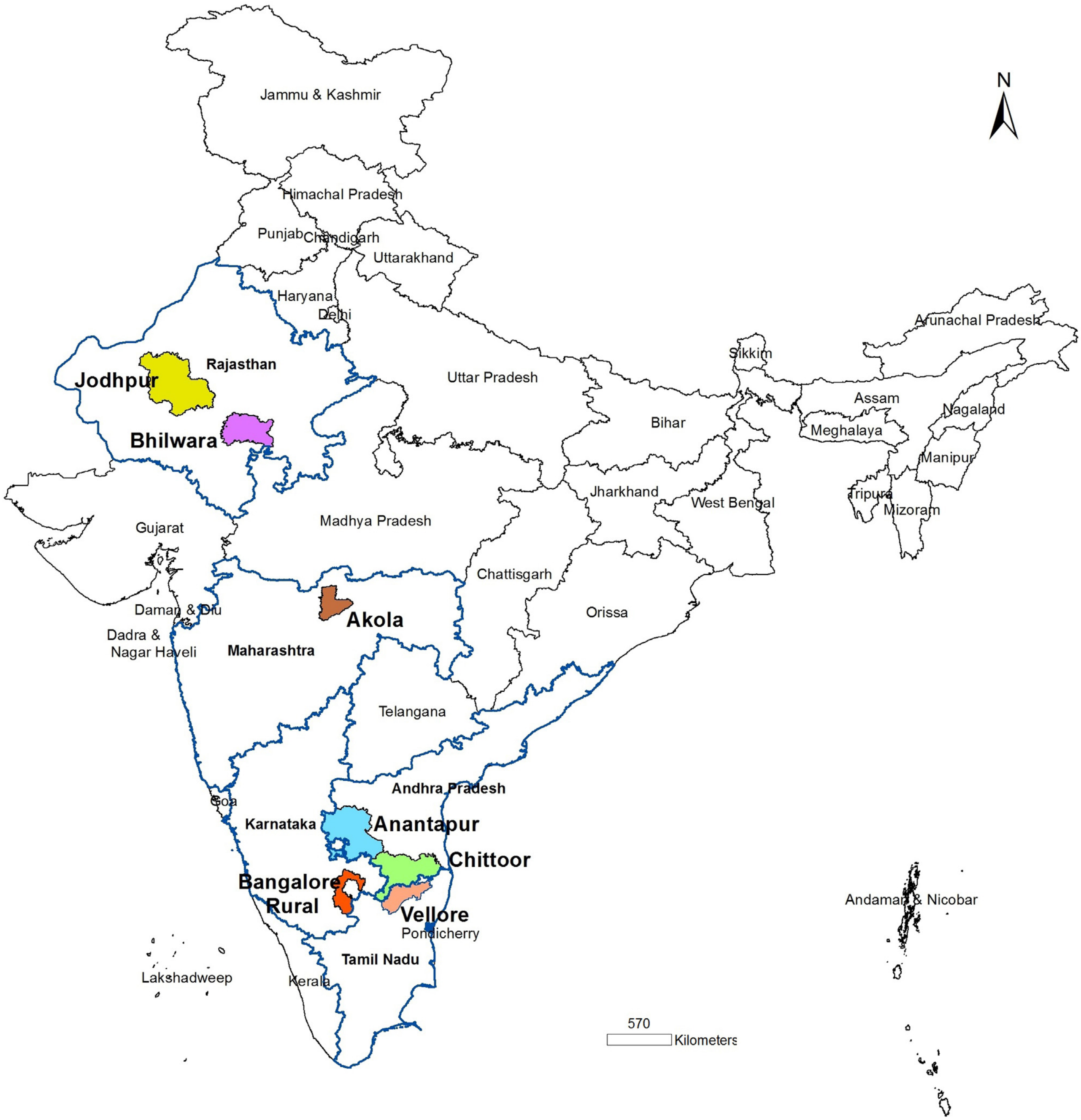

Fig. 1. Map of India indicating demarcation of districts and the location of the study area.

ticultural Mission (NHM). The size and initial investment on RWHS varied significantly in different states (Table 4). The majority of the farmers did not have water lifting devices except in Akola and Chittoor. Consequently, in the absence of a lifting device, the usage of harvested rainwater was limited to providing drinking water for livestock and humans or irrigation of fruits and vegetables. Other additional benefits included increased fodder biomass on the fringes of the RWHS, reduced soil erosion and in some cases (Anantapur and Vellore districts) recharge of the open wells. The smallholder farmers were not willing to invest in water lifting pumps available in the market (3 horse power) as its utility is for a limited period of 2–3 months in a year. Collective effort or custom hiring facility could be a solution. The numbers of fillings of the structures also indicate their potential utility. The amount of runoff collected was not always positively associated with the amount and distribution of rainfall received as it depended also on appropriateness of the location and design of pond and catchment management. Given the costs and efforts involved in harvesting rainwater, maximizing water productivity should be a primary objective. There is however, much scope for improving the current poor irrigation techniques (i.e. flood irrigation; application to high water-use systems, for example paddy rice in Chittoor) resulting in generally low WUE (Table 4). It has been demonstrated that the WUE of farm pond water could be significantly increased by using customized sprinkler and drip sets and growing high value crops and cultivars (AICRPDA, 1991; CA, 2007). The RWHS of different types- farm pond, percolation pond and *Tanka* of different sizes ($10 \times 10 \times 2.5$ m, $30 \times 30 \times 3$m, $45 \times 45 \times 3$ m; $82 \times 26 \times 3$ m; $4 \times 4 \times 5$ m among others) were constructed on individual farms under various government schemes with preference given to small-

Table 2
The indicators of composite determinants (variables) of performance of small RWHS.

Variables	RWHS as a customized package	Handholding (technical) support in the initial phase	Farmer participation level	Social networking
Indicator 1	Provision of only farm pond	Implementing agency (IA) supports only during construction of pond	Farmer contributes to the initial investment of RWHS	Household membership in self-help group (SHG)
Indicator 2	Provision of proper inlet and outlet & lining	IA supports during first crop/rainy season	Farmers has role in deciding the size and location of the pond	Household membership in community based organization
Indicator 3	Access to water lifting devices	IA is accessible at block (sub-district) level	Farmer has role in repair and maintenance	Household membership in panchayat (local body)
Indicator 4	Access to drip/sprinkler for irrigation	IA is accessible at village level	Harvested water is utilized fully	Household involvement in implementation of government development programme
Indicator 5	Awareness and access to water efficient cultivars/high value crops	IA coordinates with other relevant agencies	Level[a] of interaction among farmers and IA	Membership in any other community group
Max score	10	10	10	10

RWHS: Rain water harvesting structure.
[a] Farmers interaction with IA, once before crop season and twice every month during the season was considered appropriate by the stakeholders.

Table 3
Performance of scientist managed on-farm trials on rainwater harvesting in different agro-climatic regions (2008–2010).

Annual Rain fall (mm)	Soil type	Location (states)	Major production systems	Size of farm pond, m^3	Net Benefits $RWHS^{-1}$ $annum^{-1}$, US $	Unit cost of structure, US $	IRR, %
500–750	Alfisols, Vertisols Inceptisols	Andhra Pradesh Gujrat Rajasthan	Sorghum, castor based, Castor & groundnut Maize based	250–500	72–224	931–1397	4–16
750–1000	Alfisol Vertisol	Karnataka Maharashtra	Finger millet based Cotton based Soybean based	250–1000	102–224, 149–298	1024–1397	14–22
		Madhya Pradesh (MP)					
>1000	Inceptisols	Jammu & Kashmir	Maize based	250–300	84–186	838–1304	7–13
	Vertisols		Paddy based				
	Oxisols	Jharkhand	Paddy based	1000–2500	298–381	1862–2218	14–17

Source: AICRPDA (1991-2011).
Note: Performance of RWHS at 10 locations of CRIDA's Dryland project has been clubbed into 3 groups based on rainfall range in different regions.

Table 4
Structural characteristics of rainwater harvesting structures (RWHS) of sampled farmers.

Districts (soil type)	No. of sample farmers	Annual rainfall (mm)	Coefficient of variation of annual rainfall (2004–2013)	Major cropping system	Average land holding (ha)	Size of farm pond (m^3)	Initial invest-ment, US $	No. of fillings per year	Access to water lifting device, % farmers	Water utilized using MIS, % farmers	Inlet/outlet pitching, % pond
Chittoor (Loam)	10	934	23.1	Paddy, sorghum, mango	3.31	100–600	840	6	80	20	60
Anantapur (Alfisols)	10	553	23.7	Groundnut, castor, sorghum	3.6	150–600	536	2	10	10	10
Bangalore R (Alfisols)	20	834	27.1	Cotton, pigeon pea, chickpea	1.6	100–300	520	0.7	10	–	10
Akola (Vertisols)	20	885	29.9	Finger millet pigeon pea	6.0	900–2000	1527	4	100	90	90
Vellore (Alfisols)	20	949	18.6	Sorghum, coconut	3.05	500–1200	905	3	40	30	60
Bhilwara (Inceptisols)	10	650	22.5	Maize, groundnut	6.55	500–1000	935	1	50	10	50
Jodhpur (Aridisols)	10	327	35.5	Pearl millet, pulses	3.85	*30–50* L (*Tanka*)	850	3	20	–	90

MIS: Micro irrigation systems (sprinklers and drip).

holders. The allocation of land for RWHS even in better performing Akola district was much less (about 2% of the land holding) than required. But under similar rainfall and soil situations 6–10% land allocation has been found to be sufficient (Malik et al., 2013). In most case study farmers (90%), the guidelines of different public schemes restricted their choice on size of RWHS. Irrespective of factors such as runoff potential, land availability, farmer need, all ponds excavated under MNREGS were of the same size.

In light/red soil areas the farmers had lesser interest for unlined RWHS because of high seepage losses of harvested water. In the rainy season, when pond was full the water was not needed and during long dry spells, the water in the unlined ponds dried up because of seepage and evaporation losses. In such areas, RWHS were mainly used for recharging the open wells. Most of the farm ponds (90%) did not have any lining; however, the lining with low density polyethylene (LDPE)/high density polyethylene (HDPE) sheet or other cost effective alternate would help minimise such seepage losses in the red/sandy soil (Alfisols) area and preserve harvested water to be used during dry spells (Reddy et al., 2012; AICRPDA, 1991-2011). The seepage losses in the black soil area were minimal. In Anantapur and Bangalore, the potential benefit of water harvesting could not be realized due to seepage losses, except a few lined ponds (10%), which provided water for supplemental irrigation. Hence any public investment programme on RWHS in the red/sandy soil regions needs to include the lining of these structures. The harvested water in Rajasthan was mainly used for drinking purpose as well as to provide water to a few perennials and the kitchen garden. Traditionally, every household in arid Rajasthan had a Tanka (Goyal and Issac, 2009); however with provision of drinking water to majority of the villages through public supported bore-wells, the numbers of 'Tanka' are decreasing. However it emerged from the FGDs that the quality of groundwater in most of these bore wells is not potable due to high salt content including fluoride and this fact is indeed supported by recent groundwater analysis (Panwar and Tewari, 2015). Hence many households wanted to use harvested rainwater for drinking purpose. Since the tanka has especially designed compacted catchment which is kept clean (not used for crop production) and has sand traps, the stored water remains potable (Goyal and Issac, 2009).

3.2.1. Impacts on farm enterprises and income

Rainwater harvesting and its utilization through farm pond/percolation ponds had a significant impact on farm productivity and household income; however, their performance was indeed mixed (Tables 5–7). Though the net returns due to farm ponds were positive under scenarios, (the existing scenario with 50% support on initial investment and a scenario with no subsidy), the net returns were attractive only where high value crops/commodities utilized the stored water. For many farmers, ponds were highly useful for rainfed farming and had a multiplier effect on farm income. For example for some farmers in Chittoor RWHS resulted in diversification into fruits, vegetable and livestock production, and the annual household income doubled from a low base of around US$ 250 to more than US$ 500. This additional income includes the incremental income from rental of water pump and breeding ram. In some cases, the RWHS were viewed as a failure and a waste of productive land, labour and finance. For such farmers in Anantapur, Bangalore rural and Bhilwara, the net returns due to farm pond were very low (Table 6). The crop and livestock productivity and farm income increased significantly in Akola and Chittoor districts due to farm ponds. Supplemental irrigation resulted in an increase in productivity of different rainfed crops like pigeon pea, chickpea, groundnut, cotton and vegetables as well as mango and coconut plants which ranged from 5 to 72% (Table 5). On average the yield increase, compared to the field/plot (in the same farm) with no access to farm pond water, was 51% in pigeon pea, 55% in chickpea, 36% in cotton (water + Bt seeds) and 12.5% in soybean. In Anantapur only 20% farmers who own open well had the benefit of yield increase in groundnut by 23%. In Bangalore, only 25% farmers who had lined ponds could benefit and use the harvested water for growing 0.3–0.4 ha field-bean either sole or intercrop with pigeon pea. In better performing district Akola pond water could provide supplemental irrigation to >2.0 ha area for a household. The gross cropped area also increased by 5–26% across districts. With the availability harvested rainwater for supplemental irrigation, the farmers planted additional fruit trees and it also resulted in productivity increase of existing fruit trees, mango (39%) in Chittoor district and coconut (51%) in Vellore

Table 5
Impact of farm level rainwater harvesting on farm productivity.

District	Increase in gross cropped area, in%	Extent of increase in the yield of major crops (for 0.3–2.0 ha area), in%						Additional fruit plant, Nos.	Increase in yield of existing fruit plants, in%	Increase in livestock production[a]	
		Pigeon pea	Cotton	Chick pea	Groundnut	Soya bean	Vegetables			Bovine milk yield, in%	Small ruminant, in Nos.
Rainwater harvesting structure (Not lined)											
Chittoor	19.5	–	–	–	25	–	55	46	39	14	5
Anantapur	7.4	5	–	–	23	–	–	–	–	–	–
Akola	25.8	63	55	72	–	12.5	–	–	–	–	–
Bangalore rural	–	–	–	–	–	–	–	6	–	4	2
Vellore	5	–	22	–	18	–	–	16	51	7	2
Bhilwara	8.5	–	–	16	–	–	12	22	19	–	6
Rainwater harvesting structure (lined)											
Jodhpur	–	–	–	–	–	–	8	12	23	–	10
Bangalore rural	8.5	23	–	–	–	–	24	12	–	–	–

[a] Increase was due to improved access to fodder and water.

Table 6
Farm household's additional net returns due to farm level rainwater harvesting.

District	Scenario I (With no subsidy)			Scenario II (With 50% subsidy on initial investment)		
	Annual net current benefits[a], US$/HH	IRR,in %	Payback period, year	Annual net current benefits[a], US$/HH	IRR,in%	Payback period, year
RWHS (Not lined)						
Chittoor	140 (57–200)	12	6	210 (127–270)	44	2
Anantapur	60 (0–120)	5	10	95 (35–155)	31	3
Akola	226 (53–342)	11	6	362 (195–480)	42	2
Bangalore rural	48 (0–97)	4	11	85 (40–130)	29	3
Vellore	132 (67–167)	9	8	205 (140–236)	40	2
Bhilwara	105 (10–190)	5	10	175 ((85–260)	32	2
RWHS (lined)						
Jodhpur	126 (5–152)	5	10	195 (74–224)	21	5
Bangalore rural	116 (0–150)	9	8	160 (45–195)	29	3

Note: The figures in parenthesis indicate the range of net returns across the households; RWHS: Rain water harvesting structure; IRR: Internal rate of return.
[a] Increase was due to supplemental irrigation and diversification of crops and varieties/cultivars (net benefits in the current year).

district (Table 5). Provision of supplemental irrigation because of RWHS, not only increased the productivity of mango but also resulted in their regularized annual fruiting. Other benefits were increased bovine milk production due to increased access to crop residues/fodder and drinking water and more number of small ruminants maintained within orchards. For some farmers, the benefits of RWHS were life changing. For example inn Chittoor, additional income was gained from the higher production of mango and vegetable crops. Farmers used the income to purchase livestock, educate children, and acquire diesel operated pump sets for their own use or for hire (Table 7). Thus, income from farm ponds had a multiplier effect with additional net returns ranging from US$ 85 to US$ 362 per annum per household (Table 6). Using the harvested rainwater for producing high value crops like mango, coconut, chickpea, cotton and vegetables was the key factor that resulted in higher economic benefits from RWHS. This key finding is supported by Pareek, 1999, Kumar and Roy (2013) and AICRPDA (1991-2011).

In Akola district the crop and varietal mix changed significantly as result of farm ponds. The cropped area increased both in *kharif* (rainy season) and *Rabi* season (post-rainy); the area increased under post-rainy chickpea on black soils with one sprinkler irrigation using pond water (Table 5). Farmers' perceived risk of crop loss due to dry-spells considerably reduced due to RWHS. The farmers were willing to make more investment on costlier seeds and fertilizers. Consequently they shifted from local variety to Bt cotton (Bt's seed cost and potential yield both were significantly higher) in view of high probability of getting harvested water for supplemental irrigation. Few farmers (10%) also used ponds for aquaculture for 5–6 months and earned additional net income up to US$ 140 RWHS^{-1} annum^{-1}.

The positive impact of farm ponds on agricultural productivity as well as farm income was observed to be highest in case of Akola district followed by Chittoor and Vellore districts and it was least in Bangalore rural, Jodhpur and Bhilwara. In Anantapur, which is one of most drought affected districts in south India with predominantly red soils which have low water holding capacity, the net benefits of farm ponds were quite low. The reasons for this included high seepage losses due to no lining, poor access to water lifting devices and the fixed size of the farm ponds constructed under MNREGS did not consider farmer preference. Case study analysis and discussions with farmers suggest that RWHS with lining has good potential for drought proofing and diversification through high value crops in Anantapur district as well. For Bhilwara in Rajatshan the net benefits due to a farm pond ranged from US$ 85 to US$ 260 per annum with an average of US$ 175 (Table 6). Potential benefits could not be harnessed due to inefficient utilization of harvested water as result of lack of proper water lifting devices and micro-irrigation equipment, and low adoption of improved practices. In Jodhpur the rainwater harvested in the *tanka* was used for drinking purpose, animals and supplemental irrigation to fruit plants in the initial stages. To ensure safe to drink water quality from the tanka, the structure needed proper concrete roof with covered opening (with locking system) as well as cleaning of catchment. Most of the farmers took such measure for ensuring water quality. With 30–40,000 L RWHS, the farmers could plant 50–60 arid fruit plants, for example *Zyziphus moritiana* and *Cordia myxa* recommended for these areas (Pareek, 1999; Pareek and Awasthi, 2008). That gave an additional annual net return of US $ 195 from the third year onwards. But the adoption of small *Tanka* with horticulture plants was low mainly due to lack of awareness and knowledge, lack of capital, long payback period (>5 years) and poor targeting of farmers (Kumar and Roy, 2013). The capital requirement for a 'Tanka' of 60–70,000 L capacity, the size required to support an economically viable 1 ha orchard (Kumar and Roy, 2013), are much higher.

Provision of proper inlet and outlet of the pond with stone pitching is needed to ensure longer life and better use of the pond. But such provisions were poorly implemented in Anantapur, Bangalore rural and Bhilwara districts. Lack of access to water lifting devices in these districts also resulted in limited use of the harvested rainwater (Table 4). As emerged from the FGDs with farmers and other stakeholders, the majority of farm ponds in Karnataka were not useful because of poor water harvest due to inappropriate location, lack of technical support and high transaction costs. Many farmers considered the maintenance of farm pond as wastage of labour and land. In all, 54% of the ponds in Anantapur and 47% ponds in Bangalore rural were not appropriately located. Furthermore, inappropriate design, size and location of number of farm ponds in Rural Bangalore, Anantapur and Bhilwara districts resulted in poor rainwater harvesting efficiency. However, the ponds which were appropriately located and lined with LDPE sheet accrued benefits of US$ 160 per household in rural Bangalore (Table 6). It is very interesting that the regions that stand to win the most from rainwater harvesting (Bhilwara, Jodhpur, and Anantapur) gain the least net benefits. In these three regions, higher investment was needed to minimise the seepage and evaporation losses, but the farmers' income base was comparatively lower. Furthermore, due to a lack of awareness and exposure to the economically viable RWHS in these drier regions, many farmers were not willing to make investment but always looked for public support. There is need for enhancing awareness and better targeting of the farmers. As emerged from the stakeholders' consultations, the size of landholding, availability of farm family labour and capital, and capacity and willingness to use harvested water efficiently could be the key factors for better targeting the farmers. The package for promoting RWHS in such drier areas should include lining of the structure and water lifting

Table 7
Changes in farm practices and technology use due to rainwater harvesting.

District	Before farm pond	After farm pond
Chittoor	• Local varieties of groundnut, paddy, horse-gram, finger-millet • Few mango plants	• Improved varieties of groundnut, paddy, chilies, tomato, coriander • Sheep rearing and milking cows • Mango (50–150 farm-pond^{-1}) • Guava, papaya, drumstick, pomegranate, cucurbits on boundary of pond. • Farmers started working as an informal group to access technology and government support
Anantapur	• Groundnut, pigeon pea, sorghum	• Groundnut, pigeon pea, sunflower, *post-rainy* groundnut • Farmers wanted support to dug open wells near the drainage line together with the lining.
Akola	• Local cotton and pigeon pea, sorghum only in kharif season,	• Bt. cotton, short duration pigeon pea, chickpea in post-rainy season, sunflower, green gram, soybean • Sprinkler irrigation introduced • Farmers got encouraged to adopt improved crop management practices
Bangalore	• Finger millet, sorghum, rainfed rice, minor millets	• Finger millet, sorghum, rainfed rice, minor millets • Vegetables and perennials on the fringes of pond • Small farmer continued to earn their livelihood mainly through wages
Vellore	• Finger millet, coconut, sorghum, sugarcane in low lands	• Finger millet, sorghum, sugarcane in low lands, higher yields of coconut • Vegetables around the pond • Increased adoption of improved agricultural technologies
Bhilwara	• Pearl-millet, maize, green gram	• Pearl millet, maize, green gram • Farmers started planting fruit trees like lemon, pomegranate for stabilizing farm income.
Jodhpur	• Pearl-millet, green gram, cluster bean, moth bean	• Pearl millet, green gram, cluster bean, moth bean • Few plant of *Zizypus moritiana* and *cordia mixa* • Pond water also used for drinking purpose

device. There is need to address the questions before making investment decisions as to where and how the harvested water would be utilized economically to make the programme demand driven.

Internal rate of return: An IRR of 21–44% with a payback period of 2–5 years well demonstrates the viability of capital investment on small rainwater harvesting structures under the scenario II with 50% support on initial investment. If we consider the total cost with no subsidy on initial investment, the net returns and IRR become much lower (4–12%) particularly in the poorly performing districts. A number of other farm level studies in India have also found small RWHS economically viable with positive net present value and similar rate of returns (IIR of 7.7–15%) even at partial utilization of the structures (Panigrahi et al., 2005; Machiwal et al., 2004; Srivastava et al., 2009). However the returns, with no subsidy on capital, were comparatively higher in some of the studies in higher rainfall regions in eastern India (Panigrahi et al., 2007; Mishra et al., 2009). Without capital subsidy, the payback period was much longer as 6–11 years enhancing the risk element that would discourage resource poor dryland farmers to invest on RWHSs. However these returns were estimated based on the current farm practices, the returns are likely to be higher if the harvested water is used more efficiently for high value crops. The harvested water was an important source of potable drinking water for the farm family in Jodhpur district. Due to high risk involved in crop production, farmers in the drylands are risk averse in their investments for fertilizers, new seeds and improved natural resource management practices (Monjardino et al., 2013; Whitbread et al., 2015). Climatic variability and frequent droughts make their livelihoods more vulnerable and hence need support to sustain their family. Instead of giving direct dole and guaranteed wage employment to the rural people in such marginal environments, it would be a better option in the long run to subsidize investment on small rainwater harvesting structures. This will not only result in higher farm productivity but would build long-term productive capacity of farm households to have sustainable livelihoods. Besides these tangible benefits, farm ponds provide many environmental benefits such as minimizing run off losses, soil and nutrient loss, preserving ecosystems (Perry, 2002) and providing drinking water for animals and humans and associated health benefits. The analysis of these benefits was beyond scope of this paper. Wide variation observed in net benefits derived from farm ponds across households and districts indicate not everyone is operating efficiently. This indicates the potential for improvement and importance of better targeting the programmes for farm level RWHS. The returns were observed to be higher in area with black soils and annual rainfall >500 mm as compared to red/sandy soils and annual rainfall <500 mm. Lining of the pond was a necessity for its success in the red/sandy soils; however the lining was not important in the black soils.

3.2.2. Implementation strategies and their effects on performance of RWHS

The strategy for the implementation of programmes promoting farm level RWHS was not the same in all the districts/states and to a great extent influenced the usefulness of these structures. In 'better performing districts' such as Chittoor, Akola and Vellore, the farmers were made aware about the importance and potential benefits of rainwater harvesting in the beginning of the schemes. Dhan foundation, an NGO in Chittoor and government agricultural officers in Akola and Vellore played proactive roles in creating convergence and assisting farmers to access water lifting pumps, micro-irrigation system (MIS)-sprinkler and drip and improved seeds. Individual farmers were not willing to invest on water lifting device (WLD) and MIS, but a reasonable cooperation among them in Akola and Chittoor districts because of efforts of implementing agency and few active farmers significantly increased the access and use of WLD and MIS. Hence the farmers could see direct benefits that resulted in their increased participation. The size and location of farm pond in Chittoor, Akola and Vellore were mostly decided by the farmer and the project staff together depending on the runoff potential and farmer need. Farmers' contribution in cash, kind or labour was mandatory. Organizing farmers into self-help groups (SHGs) in these districts enabled them to share the water lifting devices and improved technology and grow high value crops. Farmers successfully worked as a community in Chittoor district; the cooperation among members increased their capacity for maintenance and repair of the structures and access to MIS, WLD and high vale crops. A sustainability fund was used for capacity building and maintainence of common structures. Within a span of 3 years, 200 new farm ponds were constructed in selected cluster of villages in Akola district. However the farmers in Bangalore rural, Anantapur, Bhilwara and Jodhpur were not imparted knowledge on the potential benefits of RWHS and their participation was poor. Lack of coordination among different departments in these poorly performing districts resulted into farmers' poor access to water lifting device, MIS, improved seeds and high value crops. Hence many farmers could not utilize the harvested rainwater efficiently as found in other case studies as well (Kareemulla et al., 2009). Though the initiatives of individual extension officers and leadership role of few farmers were the key drivers of successful implementation strategy, but creating awareness and skill building of farmers, encouraging cooperation among RWHS owners, pushing RWHS as a complete package and better targeting of farmers is likely to increase the usefulness and impact of such programmes.

3.2.3. Factors determining successful RWHS

This analysis indicates that the integration of farm pond in the dryland farming systems has great potential to increase farm productivity and income in these regions. However, its adoption and net benefits varied significantly among different households/districts/states. In the multiple linear regression analysis, the coefficients for landholding size and household assets were significant indicating that the benefits of RWHS significantly increased with an increase in the size of landholding and household assets (Table 8). This result is supported by the observation that farmers with less than 2.0 ha landholdings in dry areas were not willing to adopt farm ponds. The landholding size of our sample households was also more than 2 ha in all the districts except Chittoor and Bangalore rural. The small farmers for whom agriculture is not the major source of income, during FGD's stated that they do not want to lose land for the RWHS and adoption of RWHS affects their wage earning activities adversely as they need to allocate labour and other resources for construction and management of farm ponds. This was also supported by (AICRPDA, 1991-2011). But in few cases the adoption of farm pond was not related to land size. For example in Chittoor district, where farmers (especially women) with small landholding were engaged in high value crops like fruits (mango) and vegetables and had an opportunity to use also the nearby common lands as catchment for RWHS, there the farm ponds were found to be economically viable intervention even for smallholders. Greater availability of labour from these women farmers (lower opportunity cost of labour) also contributed to the success of the RWHS in case of smallholder farmers (<2 ha). Hence this finding calls for context specific flexibility in promoting RWHS. Validating the general perception, the positive and significant coefficient indicates that higher the rainfall better the performance of RWHS in the regions where the annual rainfall varies from 327 to 949 mm. Incorporating age of the farmers as an explanatory variable in the regression analysis interestingly shows that the younger farmers better adopt the technology to harness greater benefits from the RWHS as indicated by its negative and significant coefficient. Rerunning the regression with index for age category as an explanatory variable also shows that Younger age group (below 45 years) demonstrate the positive tendency in adopting the technology at 10% significance level (Appendix). This has a greater policy consideration, in development and implementation of development projects. These projects should target younger farmers for the implementation of water harvesting structures for greater outcome. Coefficient for access to open well was positive and significant. This is because RWHS were better used as percolation pond to recharge open wells as compared to the unlined farm pond with high seepage losses, particularly in red soil areas in Anantapur and Vellore. Positive and significant coefficient indicate that the performance was much better if there was provision of RWHS as a complete package as measured via five indicators like provision of proper inlet and outlet and lining, devices for lifting and efficient use of harvested water, access to water efficient cultivars and high value crops as indicated in Table 2. Non-utilization of harvested water due to non-availability of water lifting devices/micro-irrigation system or lack of appropriate crops/cultivars discouraged its adoption (Kareemulla et al., 2009). The village level handholding (technical) support to the farmers in the initial stages (especially for the first two years) was very important for the success of rainwater harvesting programme (CA, 2007). The positive and highly significant regression coefficient indicates that farmers' easy access to technical support in the initial stages (especially first two years), which was measured through different indicators as mentioned in Table 2, would result in better performance and greater benefits from RWHS (Table 8).

It was crucially important to decide the appropriate size and location of the RWHS depending on the runoff potential and slope of the catchment area; this calls for the involvement of technically qualified staff. Since a small proportion of farmers (not more than 10% in a village) opted for the RWHS, practically the every pond also collected the run off from outside the farmer's own field during the heavy rainfall events. In many cases except Akola, Vellore and Chittoor, the location of RWHS was not technically appropriate and was decided either on the basis of convenience of farmer or the contractor who dug these structures.

Another factor which positively influenced the performance of RWHS was the 'level of farmers' participation' which was captured by indicators mentioned in Table 2 like level of farmers contribution and their role in decision making with regards to construction and maintenance of RWHS as well as frequency of interaction with the implementing agency. Kareemulla et al. (2010) also observed similar findings in Anantapur district. The nature of association between the dependent variable- the area irrigated using harvested water (AIHW) and most significant explanatory variables like landholding size, household's assets and indices for village level technical support and RWHS as package is further illustrated in Fig. 2.

3.2.4. Scaling up

Despite the proven economic viability of small RWHS and their potential to enhance farm productivity and systems resilience, the majority of non-adopting farmers in dryland areas were not willing to invest in this activity (Table 9). The survey revealed the following key reasons:

[v]

i Lack of awareness and knowledge about its potential benefits.
ii Lack of funds to pay for initial investment on RWHS and long payback period.
iii Reluctance to allocate precious land for the structures.
iv Small net benefits from small RWHS (wages from off/non-farm were a major source of livelihood for smallholders).
v Difficulties in accessing technical and financial support for RWHS.

Table 8
Estimates of the determinants of performance of small rainwater harvesting structures.

Explanatory variables	Regression coefficient	Standardized coefficient	Std. error	t-value
Intercept	−0.8442		0.335	−2.520
Land holding size	0.0637**	0.1733	0.023	2.739
Age of HH head	−0.0097**	−0.0980	0.005	−2.051
Education of HH head	−0.0059	−0.0198	0.014	−0.411
HH assets '000 INR'	0.0019***	0.2057	0.001	2.936
Access to open well (0 or 1)	0.7092***	0.0841	0.108	6.585
Indices for level of farmers' participation (0–10)	0.0401*	0.2448	0.023	1.714
Indices for social networking (0–10)	0.0232	0.0487	0.030	0.767
Indices for RWHS as package (0–10)	0.1679***	0.3289	0.033	5.013
Indices for village level technical support in initial stages (0–10)	0.1195***	0.2396	0.037	3.200
Annual rainfall, mm	0.0004*	0.0750	0.000	1.719
Coefficient of determination (R^2)	0.9050			
Adjusted R^2	0.8930			

Note: *significant at 0.1; **significant at 0.05; ***significant at 0.01.

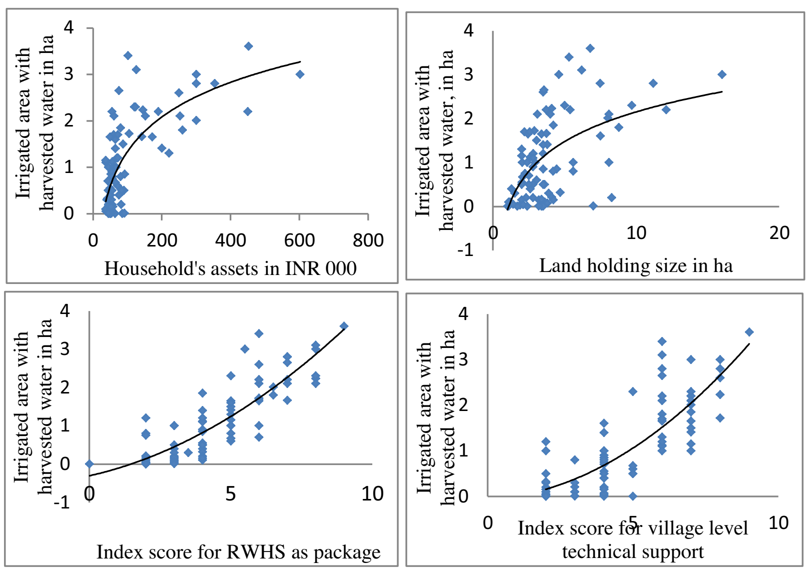

Fig. 2. Illustration of relationship between 'irrigated area with harvested water' and important explanatory variables.

Table 9
Non-adopting households' awareness and reasons for their unwillingness to adopt RWHS.

Characteristics	Jodhpur (n = 10)	Bhilwara (n = 10)	Akola (n = 20)	Anantapur (n = 10)	Chittoor (n = 10)	Vellore (n = 20)	Bangluru rural (n = 20)	Total (n = 100)
Awareness on RWHS	10	7	18	6	9	12	8	70
Knowledge of someone who has RWHS	10	6	18	3	8	12	8	65
Ever visited such structure	10	4	17	2	7	8	6	54
Awareness on the process to get government support for RWHS	3	2	11	3	4	8	6	37
No. of respondents not willing to invest in RWHS	9	10	8	10	9	16	18	80
Reasons for unwillingness to invest/adopt								
Lack of funds	9	9		8	7		16	78
Difficult to part with land for the purpose	2	4		6	6		14	51
Not sure of viability of investment	5	7		9	2		18	57
Not sure of sufficient water to fill the RWHS	4	6		7	1		16	46
Not sure of technical feasibility of RWHS	0	7		6	2		14	41
Not sure of usefulness of harvested water	7	7		9	0		14	47
Difficult to get access to government support	9	8		4	7		14	64

3.3. Technology, policy and institutional needs

In the intensively worked watersheds, investments in water harvesting systems may result in severe water trade-offs with downstream users and ecosystems (Calder, 1999), but the other evidence indicates limited or no downstream impacts on stream flows from broad implementation of small scale water storage systems (Schreider et al., 2002; Sreedevi et al., 2006). Investing in water management in rainfed agriculture can have positive environmental impacts on other ecosystems as a result of reduced land degradation (Raju et al., 2009; Wisser et al., 2010). There could be positive as well as negative externalities of small RWH but there remains a large research gap related to hydrological and social impact on watershed scale (Glendenning et al., 2011; Bouma et al., 2011). There is need for location specific planning and limit the number of structures that considers runoff potential and alleviates upstream and downstream inequality (Glendenning et al., 2011). Furthermore, encouraging a common platform for the farmers and other relevant stakeholders at cluster of villages' level could help in better planning and minimise negative externalities of RWH. A new approach is needed directing investments in creating awareness on long term benefits, human capacity, specific technologies and institutional development for promoting small scale RWHS.

The construction of RWHS is both capital and labour intensive process. Since capital is the major constraint for the dryland farmers, capital subsidy is a necessity. Though there are provisions for creating RWHS under different public programmes in India like IWMP, MNREGS, NHM, RKVY, among others; but our study shows its low adoption and wide gap in the benefits from the RWHS across farms and regions which is mainly due to institutional and policy gaps- this was also supported by CA (2007) and Kareemulla et al., (2010). Based on the study of determinants and FGDs with farmers and other stakeholders we propose the following technology, policy and institutional arrangements:

3.3.1. Policy and institutional needs

- Need inter-departmental committee at district level to better target public support with flexibility to decide the size of the structure.
- Operationalize the farm pond/RWHS as a customized package (including inlet and outlet pitching and lining of pond, water lifting pump, micro-irrigation system, improved crop management practices and improved cultivars of farmers' choice) through effective convergence. Participatory preparation of integrated action plans at the level of a cluster of villages or a mega watershed may help in promoting such convergence.
- Need to launch massive awareness campaign on the need and benefits of farm level rainwater harvesting.
- Provision of technical support at village level especially in initial phase: Extension worker/creating service provider farmers (handholding support, equipment, liaison work, follow up until the experimental stage is finished).
- Creating water harvesting self-help groups (SHGs) would improve access to technology and minimise transaction cost through mutual learning and cooperation.

3.3.2. Technology needs

- Low cost and user friendly water lifting devices and efficient micro-irrigation system customized for smaller scale use.
- Technical person and the farmers should have a major say in deciding the location and design of the RWHS.
- Capacity development on micro-irrigation systems and optimal use of harvested water.
- Generate maps on rainwater harvesting potential at different scales.

4. Conclusions

This study proves that the farm level rainwater harvesting has a great potential to improve productivity and farm income in dryland areas of India, given the availability of appropriate technology, policies and institutions and capital support for initial investment. Using participatory processes, it is of critical importance to decide the appropriate size and location of the RWHS depending on the runoff potential, slope of the catchment area and the willingness of farmers to invest resources. The productivity of harvested water is maximized when efficient application methods (e.g. micro irrigation) and high value crops are targeted. Farmers should have access to information on different options for using harvested water along with improved management practices and market opportunities. Farm level RWHS must be implemented as a customized package. This is best done via participatory approaches with effective facilitation by technically qualified and trained personal at the village level and through convergence of relevant schemes. Targeting younger farmers for the implementation of water harvesting structures would result in greater outcome. Location specific planning should consider runoff potential and alleviates upstream and downstream inequality. Encouraging a common platform for the rainwater harvesting farmers and other relevant stakeholders at cluster of villages' level or sub-district level could help in better planning and minimise negative externalities of RWH. A new set of extension services are needed by making trained staff available to support farmers in water management investment at small scale. The findings of this study could be very useful in better targeting of water resource development as part of recently launched mega programme of government of India Pradhan Mantri Krishi Sinchai Yojana- Prime Minister Agriculture Irrigation Scheme.

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