Scaling-up agriculture water management interventions for building system resilience in Bundelkhand region of Central India

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Summary

This case study provides evidence for combating drought, and achieving sustainable crop intensification, in rainfed areas of Bundelkhand region, Central India. The Garkundar-Dabar and Parasai-Sindh watersheds were developed as proof of concept by the Indian Council of Agriculture Research-Central Agroforestry Research Institute (ICAR-CAFRI) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) between 2006 and 2016. This study indicates pathways for harnessing the potential of rainfed areas by implementing various agricultural water management (AWM) interventions. Rainwater harvesting measures, especially rejuvenation of the *haveli* system (traditional rainwater harvesting system of the region), along with various *in situ* water harvesting interventions, were found promising for addressing water scarcity and strengthening various ecosystem services. Water harvesting measures, improved agricultural practices (such as balanced fertilizer application, introduction of climate-smart crop cultivars, weed and pest management) and supplemental irrigation, enhanced crop yield by 30-50% and cropping intensity from 80 to 150%. Enhanced groundwater availability (2-2.5 m additional head) helped to reduce crop risk, through the availability of supplemental irrigation and enhanced cropping intensity, as large areas of fallow land were converted to cultivation. AWM interventions also helped to enhance base flow (35-42 days to 110-122 days), control floods, soil erosion and land degradation (by about 33%), and enhance land and water use efficiency (40-70%). Since 2017, lessons from these model watersheds have been scaled up in all seven districts of Uttar Pradesh Bundelkhand region, by an ICRISAT-led consortium. This study explores the potential of rainfed areas that are achievable through the adoption of AWM interventions. It suggests that the role of extension, through capacity building and exposure of various stakeholders to AWM, is key to harnessing the potential of drylands. In order to further scale up such innovations to the entire region, it is important to involve knowledge generating and knowledge dissemination institutes, along with central and federal machineries. Involvement of private and non-governmental organizations as well will help achieve system level outcomes.

1. Introduction

India is one of the fastest developing economies in the world, with large human resource availability. Agriculture is the major source of livelihoods for about 55% of the workforce. The country has 142 million ha of cultivable land. About 55% of this is under rainfed systems, which provide about 45% of India's food requirements (GoI, 2015). Rainfed agricultural lands suffer largely from water scarcity, land degradation and low productivity, which coincide with widespread poverty and malnutrition (Rockstrom and Karlberg, 2009). To address such problems, India has since the 1960s adopted a holistic approach of integrated natural resource management for sustainable crop intensification, with the introduction of river valley projects to ensure food security. This has evolved over time with new lessons and experiences. Between 1970–80, the focus was mainly landscape protection and erosion control, with the implementation of field bunding as an *in situ* soil conservation measure. This benefited the community, but due to its compartmental nature the full potential benefits were not realized. As the approach followed was contractual, community participation was lacking. This is crucial for the sustainability of AWM interventions. The approach was modified in subsequent decades (1990s), and a water conservation component was also included. A number of rainwater harvesting structures were constructed, which generated benefits in terms of increased groundwater recharge and crop intensification. Although there was increased groundwater availability, farmers in rainfed areas were cultivating traditional, poor yielding crop cultivars. To improve the productivity of small and marginal farms a new productivity enhancement concept was introduced in the late 1990s. This was crucial to addressing food insecurity along with crop intensification. Further, to ensure participation and address equity in benefit sharing, efforts were made to include the landless and women (Figure 1).

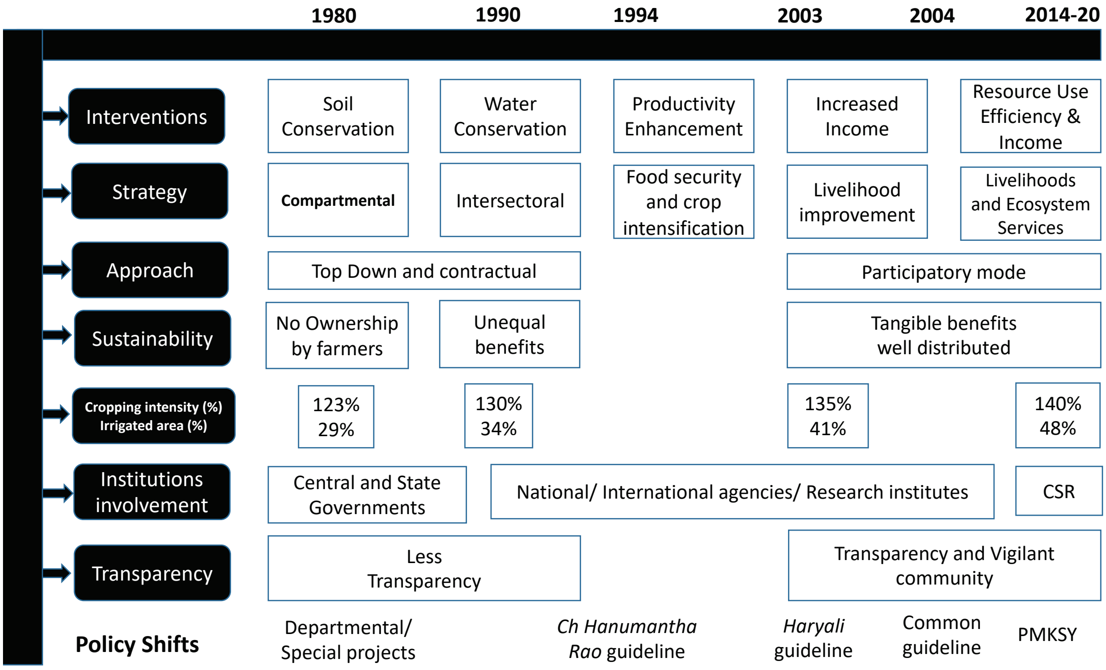

Figure 1: Journey of watershed management programs in India since 1980
Source: Authors' elaborations based on literature review

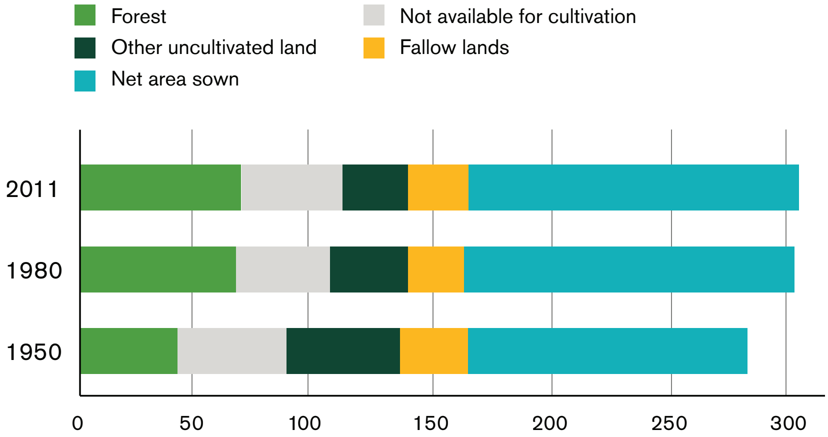

Figure 2: Land use, or land cover status, in India from 1950 onwards (in million ha). Total geographical area of the country is 328.27 m ha. However, this figure only shows areas for which land use statistical data is available (Data source: GoI, 2015).

With the aim of addressing social equity, the Government of India enacted a corporate social responsibility law in 2013. This requires every company with a net worth of about 80 million USD or more, to spend 2% of total earnings on social welfare programs such as education, health, sanitation, and agriculture (GoI, 2014). After realizing the potential of such investments for improved natural resource management, a significant amount of corporate social responsibility (CSR) funds began to be diverted to AWM interventions.

Figure 2 shows the change in land use, or land cover status, in India from 1950 onwards. The net sown area has been increased from 118 million ha in 1950, to 140 million ha in 1980, by converting fallow and wasteland to cultivation. Further, permanent pasture land has increased from 6.68 million ha to 11.97 million ha between 1950 and 1980, and slightly decreased by 2011.

Figure 3 describes the change in source-based net irrigated area in India since 1950. It is evident that the total irrigated area in the country has

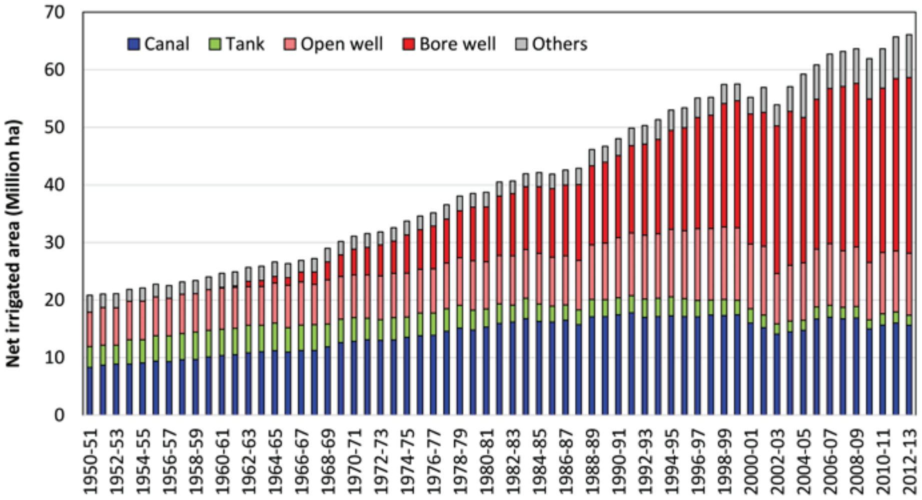

Figure 3: Change in source-based net irrigated area (million ha) in India between 1951 and 2013 (Data source: GoI, 2015)

increased from 20 million ha in 1950 to about 65 million ha in 2013. Until 1970 irrigation sources were surface and open wells or tanks. Despite a huge public investment made in order to enhance surface irrigation (major reservoirs, canal command areas), this contributed merely 18 million ha out of the 65 million ha net area irrigated in 2013. Groundwater resources (open and borewells) contributed nearly 40 million ha, largely through farmer led private investments. With increases in pump technology and energy subsidies, large amounts of rainfed areas have been brought under supplemental irrigation. As such there are no areas left that are completely rainfed. Large-scale welfare schemes by the Government of India (e.g., watershed programs, Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), etc) have also supported such developments[1]. Therefore, in this study a rainfed system is not only referring to completely rainfed, but also capturing supplemental irrigation.

A number of impact studies that have been undertaken by different agencies. These reveal that 99% of watershed works generate a benefit-cost ratio of more than one. However, there is a skewed distribution. High performing watershed projects are from knowledge-based institutions in which needs based, science led interventions were implemented (Joshi et al., 2008, Wani et al., 2008, 2011, 2020; Garg et al., 2011, Singh et al., 2014). Watersheds representing medium rainfall, ranging from 700-1000 mm, performed relatively better, as interventions addressed water scarcity and these watersheds were not prone to floods. However, there is huge scope for improvement in designing and implementing interventions. For example, increasing climate variability must now be addressed when designing them. This study of a rainfed dominated, agro-ecological landscape in the Bundelkhand region, describes innovations in AWM interventions at the community and watershed scale. It details interventions, actions, and outcomes in terms of rainfed production and productivity, alongside selected social and environmental impacts. Based on this case, the scaling up approach to intensify rainfed agro-ecological landscapes, which ICRISAT and partners have been involved in since 2006, is then discussed.

2. Bundelkhand region, Central India

Bundelkhand is a hotspot of water scarcity and land degradation, vulnerable to climate variability. The total area of the region is 2.94 million ha, of which 69% is net sown area, 8% (0.236 million ha) under forest, with the rest under non-agricultural use, barren or cultivable waste (Gupta et al., 2014). The region has experienced severe drought conditions in six of the last ten years. Long term weather data, monitored at Jhansi station (a district of Bundelkhand), shows that annual average rainfall in the study region is 877mm (standard deviation, $\sigma = 251$mm), about 85% falling between June and September. The number of rainy days during the monsoon, and non-monsoon, periods are on average 42 and 13, respectively. As shown in Figure 4, long-term data analysis reveals that average annual rainfall has decreased from 950mm (1944-1973), to 847mm (1974-2004). This reduction was mainly due to the decreased number of low (0-10mm) and medium (30-50mm) rainfall events (Figure 4). Similarly, the total number of rainy days in a year also decreased. This has had an adverse impact on the regional scale water balance, especially in terms of groundwater recharge (Singh et al., 2014). It also has severe implications for the rainfed production system, in terms of a bias towards events of greater volume and intensity, and fewer events per season, affecting soil moisture patterns for crop growth.

A study undertaken by Rao et al. (2013) on climate change in the Bundelkhand region showed that about 581,000 ha, which had previously experienced a semi-arid, moist climate, has shifted towards a drier climate (both semi-arid dry and typical arid climates) as shown in Figure 5. Jalaun and Jhansi districts have witnessed great changes in climate between 1961-1990 and 1991-

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[1] *https://www.india.gov.in/my-government/schemes*

2013. Jalaun has lost all its semi-arid moist areas (233,000 ha), which have become drier, 167,000 ha becoming semi-arid dry climate areas, and 66,000 ha becoming typic arid climate. Perhaps this is the first time that the typic arid climate type has been seen in Jalaun district. Hamirpur district also witnessed about 2,000 ha changing to typic arid climate. Jhansi district also shows a large shift with 213,000 ha of semi-arid moist type becoming semi-arid dry type. Lalitpur and Chitrakoot districts also show increasing dryness. Out of seven districts, only two (Mahoba and Banda) show a slight increase in wetness. They have more areas under semi-arid moist climatic type now compared with the period between 1961-90. This affects about 9.6 million people in the Mahoba and Banda region (~0.35 million households) (Gupta et al., 2014).

Agriculture, and related sectors, are the main rural population livelihood sources (Shakeel et al., 2012). A diverse cropping system is followed in Bundelkhand; groundnut, black gram, sesame, and millet are the main crops cultivated during the *Kharif* season (June/July-October/November). Wheat, chickpea, barley, mustard, and lentils are grown during the *Rabi* season (November/December-February/March) (refer to crop calendar in Table 1). Due to undulating topography, poor groundwater potential, high temperatures and highly variable rainfall, agricultural productivity is very low (0.2–2.0 t ha^{-1}). Most areas are single cropped, completely under rainfed conditions, during the two cropping seasons. Bundelkhand is largely dependent on groundwater resources for domestic and agricultural use. Water levels in open and dug wells (4-8 m deep) deplete very fast after the monsoon (November-May). Communities suffer from water scarcity, especially in summer. Bundelkhand has 44% of cropland under irrigation, out of which 41% is under surface irrigation schemes (canal command area), and 59% irrigated through groundwater sources (dugwells and borewells) (Gupta et al., 2014).

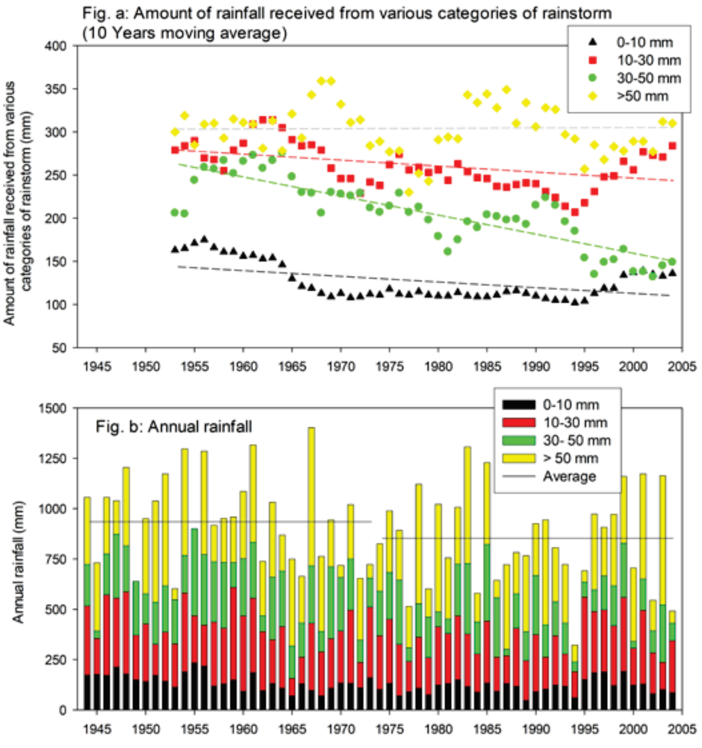

Figure 4 (a): Moving average (10 years) of rainfall received from different categories of rain events between 1945 and 2004; (b) Comparing annual rainfall between 1945-1974 and 1975-2004
(Data source: India Meteorological Department, 2005;)

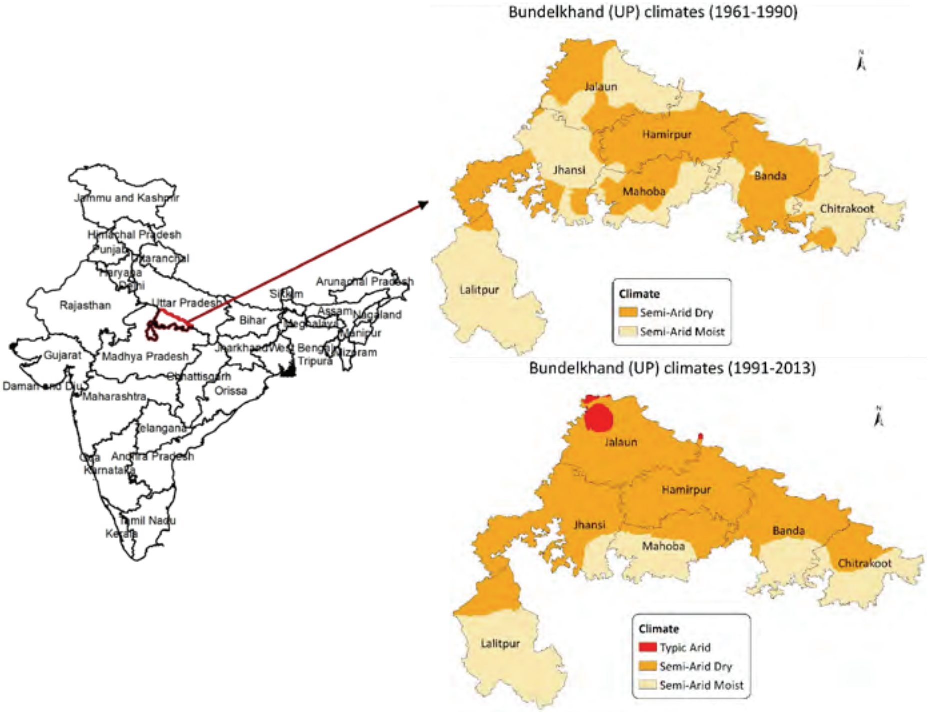

Figure 5: Change in climate patterns at district level in the Bundelkhand region (Source: Rao et al., 2013)

The socio-economic status of Bundelkhand is characterized by high poverty (30-55% across districts), low literacy rates (57%, and women's literacy is a mere 43%), and high vulnerability of women and landless people, due to adverse climatic conditions (NITI Aayog, 2016). The operational landholding size in Bundelkhand is 1.53 ha. About 77% of land owners own just 39% of the land (NITI Aayog, 2016), which shows the skewed distribution among the farming community.

A large gender equity gap exists Bundelkhand. Women are deprived of basic opportunities as they are largely engaged in domestic chores (fetching drinking water long distances, cattle management, collecting fuel wood, preparation of dung cakes, etc.) and affected by drudgery. Due to the lack of livelihood opportunities, a large portion of the male population migrates to nearby cities or to secure labour work (mining, masonry, or as a security guard or driver) leaving women and livestock behind. This has led to various socio-economic shocks affecting women, with a high rate of drudgery. Further, the nutritional status of women and children is very poor, leading to poor health (Varua et al., 2018; Mitra and Rao, 2019; Padmaja et al., 2020).

Inappropriate policies relating to natural resource management have led to failures in formal and informal institutions and a lack of collective action. Results include; defunct traditional rainwater harvesting systems (*haveli* system), weakening of the agro-pastoral system, inequitable distribution of the benefits derived from natural resources, and the loss of various ecosystem services (declining base flow, deforestation, land degradation) (Sahu et al., 2015; Meter, et al., 2016; Reddy et al., 2018).

In order to meet local and national food and water security ambitions, alongside rural development targets, there is a need to improve the rainfed dominant livelihood systems. The situation is a complex mix of climatic and environmental changes, alongside policy and social inertia (or in some cases collapse). Mobilizing capital and knowledge to progress from this state is particularly challenging in rainfed systems.

3. Pilot sites for rainfed systems intesification

This study presents the experience of two mesoscale watershed pilot projects, in the Bundelkhand region, which were then followed by scaling up initiatives (Figure 6). The Garkunder-Dabar (GKD) watershed is located in the Tikamgarh district of Madhya Pradesh. Interventions there were conceptualised and implemented by ICAR-CAFRI between 2006 and 2011. The Parasai-Sindh (PS) watershed interventions were implemented jointly by ICRISAT and ICAR-CAFRI between 2012 and 2016. Both watersheds are part of the Betwa river catchment of the Yamuna sub-basin. Yamuna is one of the tributaries of the Ganges (Ganga) River in Northern India, a large portion of the sub-basin lies in Bundelkhand region. The location of Bundelkhand is such that it acts as a gateway between the north and south of India, and it has previously acted as political hub (Tyagi, 1997). A large number of the inhabitants of the Bundelkhand region are mainly dependent on rainfed crops, and livestock based activities. Approximately 33% of the total geographical area is covered by degraded forest, grazing land and wasteland (UPWSRP, 2001). Due to undulating topography, high temperatures, and poor and erratic rainfall, agricultural productivity in the region is poor.

The total geographical area of the GKD watershed is 850 ha. Of that, 264 ha is agricultural land, the rest covered by deciduous forest or wasteland. The PS watershed is 1250 ha, 90% of which is under agricultural use. The topography of the GKD watershed is steep with slopes ranging from 2-15%, whereas slopes in the PS watershed are relatively flat (1-3%), see Table 2a.

Soils in the region are reddish to brownish red in color (Alfisols and Entisols), shallow (10-50cm),

Table 1: Crop calendar for major crops in Bundelkhand region; Kharif season coincides with the monsoon whereas the Rabi season coincides with winter (Source: Singh et al, 2014; Garg et al., 2020)

Season	Crops	Crop Duration (days)	Irrigation status	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Kharif	Black gram	70-75	Rainfed		■	■	■								
	Sesame	70-75	Rainfed		■	■	■								
	Millet	90-100	Rainfed		■	■	■	■							
	Groundnut	110-120	Rainfed		■	■	■	■							
	Sorghum	120-130	Rainfed		■	■	■	■							
	Pigeonpea	200-240	Rainfed		■	■	■	■	■	■	■	■	■		
Rabi	Mustard	110-130	Rainfed					■	■	■	■	■			
	Lentil	110-130	Rainfed					■	■	■	■	■			
	Chickpea	120-130	1-2 irrigations						■	■	■	■	■		
	Field pea	120-130	1-2 irrigations						■	■	■	■	■		
	Barley	120-130	2-3 irrigations						■	■	■	■	■	■	
	Wheat	120-140	3-5 irrigations						■	■	■	■	■	■	

coarse gravelly, light textured with low water-holding capacity in the root zone (80–100mm/m), and low levels of nitrogen, phosphorus and organic carbon. Groundwater is the primary water source for domestic and agricultural use. Borewells do not work in these areas due to the hard rock aquifers (granite) and poor specific yields (<1%). Landscape topography, land use and demographic details of study watersheds are shown in Tables 2a and 2b.

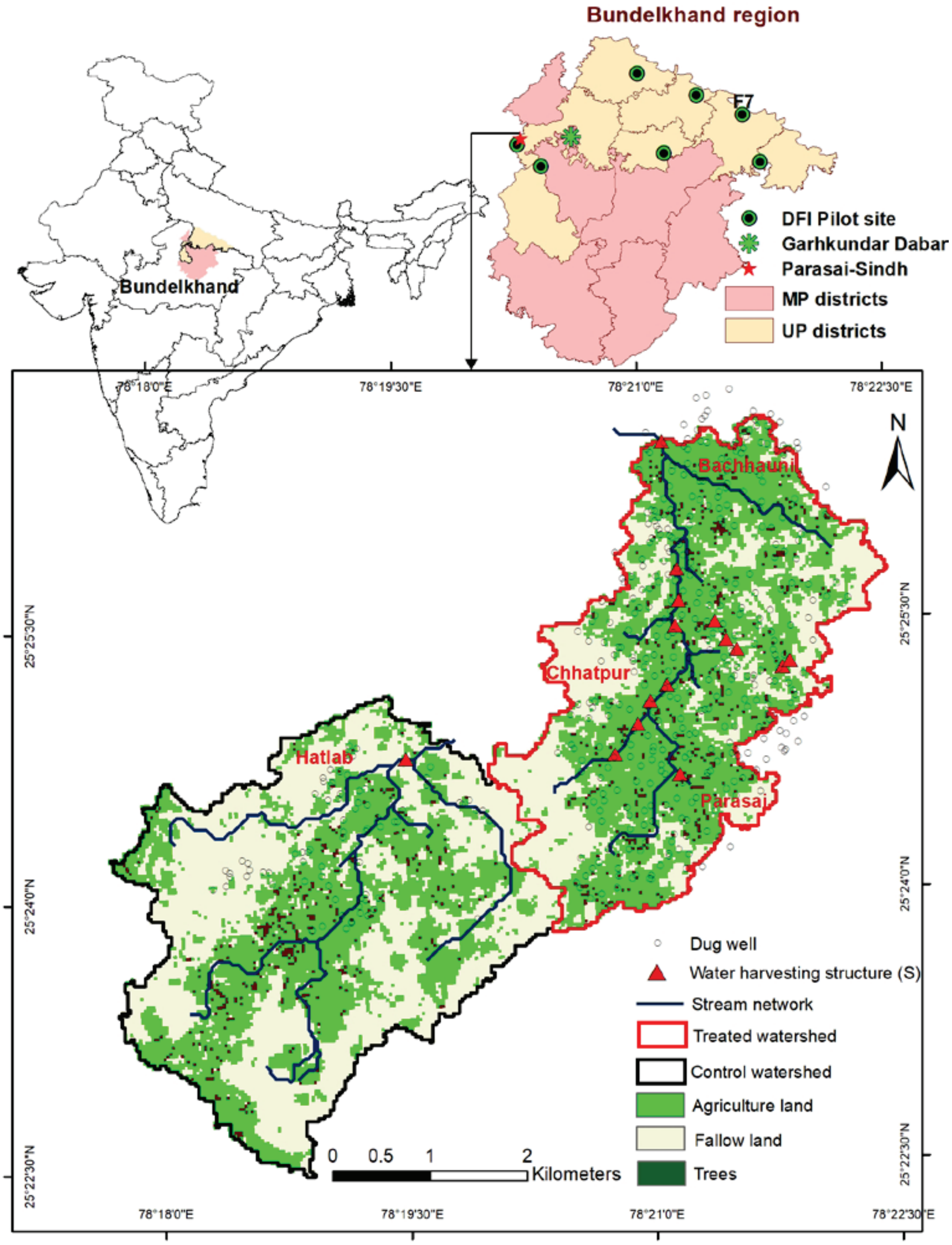

Figure 6: Location of pilot watersheds in Bundelkhand region (Source: Garg et al, 2020)

Table 2a: Landscape topography, land use and demographic details, along with socio-economic and environmental impact indicators of the GKD and PS watersheds, and nearby control watersheds (Garg et al, 2020; Singh et al, 2014)

Indicator	**Garhkundar-Dabar Ws (treated)**	**Control** **Shivrampur Ws**	**Parasai-Sindh Ws (treated)**	**Control**
State	Madhya Pradesh	Madhya Pradesh	Uttar Pradesh	Madhya Pradesh
District	Niwari (erstwhile Tikamgarh)	Niwari (erstwhile Tikamgarh)	Jhansi	Jhansi
Villages	Garhkundar, Shivrampu, Rautiana, Dabar, Sakuli, Ubaura	Shivrampur, Dabar	Parasai, Chhatpur Bachhauni,	Hatlab
Project period	2006-2011	2006-2011	2012-2016	2012-2016
Location (Lat/Long)	270 27`N; 780 53` E		25º 23' 47.6" N; 78º 22' 33.0" E	
Watershed area (ha)	850	298	1246	1100
Population	980	325	3000	2800
No. of households	152	36	417	395
Land use				
Agriculture	260	136	1105	950
Degraded forest	506	125	6	26
Wasteland (Scrub land)	40	16	66	45
Other	44	20	69	79

Table 2b: Other impact indicators of GKD (2006-2011) and PS (2012-2016) watershed, and nearby control watersheds (Data source: Singh et al., 2014; Garg et al, 2020)

Indicator	**Garhkundar-Dabar Ws (treated)**	**Control** **Shivrampur Ws**	**Parasai-Sindh Ws (treated)**	**Control**
No. of days baseflow received	110	35	122	42
Average annual soil loss (t/ha)	1.5-6.5	3-11.5	1-4.3	4-13.6
Storage capacity of *ex situ* WHS (m^3)	25000	5000	115000	15000
Harvesting ratio to total storage capacity	8.2 – 9.5	2-3	3 to 7	1.5-3
No. of dug wells	116	42	388	296
Average depth (m)	8.7 (std 2.4)	8.7 (std 2.2)	9.2 (std 1.5)	10.5 (std 1.6)
Average water table depth (m)	4.6	3.3	4.9	2.9
Average pumping hours	125	62	156	86
% wells dry in December	1.7	21	3	19
% wells dry in May	3	38	5	32

4. Rainfed crop systems innovations and practices promoted

Multiple technologies and practices were introduced in consultation with; farmers, the community and the research team. Based on consultations, some existing technologies were improved, and others were introduced as new practices to the area. Here we list the principal strategies and social approaches, relating to farming system technologies, used to achieve agricultural intensification of the rainfed systems.

In situ and *ex situ* water conservation measures

Soil and water conservation practices are categorised into: *in situ* measures, and *ex situ* measures. *In situ* measures enhance soil moisture availability, and reduce non-productive evaporation through various agronomic and engineering interventions. These facilitate the harvesting of rainfall where it falls. Contour farming, field bunding, terracing, broad bed furrow, and mulching are examples of *in situ* measures. *Ex situ* measures are interventions that harvest and store surface runoff at different landscape scales, through the construction of low-cost, water harvesting structures such as farm ponds, tanks, check dams, percolation tanks and the *haveli* system.

Field bunding and agroforestry

In situ water harvesting (e.g. contour/graded bunds) enhances soil moisture availability and controls soil erosion (Garg et al., 2011; Singh et al., 2014). Larger fields are divided into smaller sizes, such that the runoff velocity is reduced, and a fraction of the runoff is harvested across the field bunds. The cross section of these bunds is about 0.8-1.0 m^2. Field outlets, with stone pitching, were constructed to guide the disposal of excess runoff. Deciduous teak trees, a suitable species, were planted at the base of the field bund, at three meter intervals, to strengthen the bund and also as an additional, long-term income source income for farmers.

Rejuvenation of *haveli* tanks

A number of public welfare programs (PMKSY, Watershed Development Program, MGNREGA) are being implemented to mitigate droughts. Recognising the importance of the *haveli* structures, which comprise a traditionally built tank to collect surface runoff, significant efforts were made by farmers in collaboration with project team to repair and maintain them. However, during heavy downpours earthen embankments were eroded, despite the thick embankment walls, because soils in this region have poor binding ability (having course texture and poor in organic matter). Rodent burrowing also led to embankment damage. Thousands of such structures, currently defunct, are found in Bundelkhand. These hold large untapped potential for rainwater harvesting (Shah, 2003). To capitalise on these, ICAR-CAFRI and ICRISAT introduced the core-wall concept, beneath the entire *haveli* embankment wall, and built safe outlets at suitable locations, to dispose of excess runoff. A reinforced cement stone wall, with a foundation up to 2m deep, was built to a suitable height for harvesting surface runoff. The core wall was then covered with soil, so that it is not exposed to harsh weather, enhancing its stability and lifespan. Identification of appropriate sites, adoption of suitable designs appropriate to the location, hydrology and other safety parameters, were important aspects of rejuvenating the *haveli* system.

Generally, *haveli*s occupy only 2-3% of the village landscape, and submerge upstream areas during the rainy season. Provision to draw water from the *haveli* structure is given so that after September/October farmers can empty the tank and utilize the fields for *Rabi* cultivation. The productivity of the *haveli* fields is relatively high since they hold more moisture, humus and nutrients. Increased groundwater availability also helps in intensifying cropping to a large extent. The life expectancy of the structure can be greater than 50 years, when constructed in stone, and with proper provision for draining excess rainwater.

Table 3 compares the unit harvesting cost of different structure types (*ex situ*). *Haveli* structures are found to be more cost effective, as they harvest surface water and also have a long life span compared to other structures, such as farm

Table 3: Comparative analysis of the unit cost of different types of water harvesting structures (Source: Authors' elaborations based on primary data collection)

Structure type	**Harvesting capacity (m^3)**	**Unit harvesting cost (USD/m^3)**	**Life span (years)**
Haveli structure	30000-50000	0.40	> 50
Farm pond	300-1000	1.25	15-20
Check dam -ICRISAT/CAFRI	1500-5000	4.00	20-30
Check dam - Govt. Dept.	1500-5000	10.00	5-10

ponds and check dams. Construction of *haveli* submerge 2-3% of community or private land, so the stakeholders must agree to implement them. During the monsoon period this land is submerged. However, farmers then have the opportunity to cultivate post-monsoon crops, with the benefits of residual moisture and increased decomposed organic carbon levels, resulting in greater productivity (Sahu et al., 2015).

Construction of check dams

To enhance groundwater recharge, a series of check dams along the drainage line were constructed following the ridge to valley approach. These check dams are reinforced stone masonry structures, nearly 1.5-2 meters in height, with a rectangular weir to dispose of excess surface runoff during flood events. Storage capacity of these structures is between 2000m3 and 10,000m3 depending on drainage density, topographical features and stream width.

Famer participatory demonstrations

There is a yield gap in rainfed crop production in Bundelkhand region, which can be bridged through various land, water, nutrient and crop management interventions. For example, the average yield between 2010 and 2014 obtained in Bundelkhand was 2180kg ha^{-1}, compared with 2988kg ha^{-1} in Uttar Pradesh overall, and 3060kg ha^{-1} across India. Similarly, chickpea yield in Bundelkhand during the same period was 770kg ha^{-1}, compared to 950kg ha^{-1} in Uttar Pradesh overall, and 940kg ha^{-1} across India. Many farmers in Bundelkhand follow conventional crop management practices, due to lack of knowledge, poor infrastructure, poor affordability and risk aversion. To raise their awareness, and knowledge, of improved practices, ICRISAT and partners demonstrated best management practices, with farmer participation (including women and youth), with the aim of fostering higher productivity. A number of best agronomic management practices were introduced and showcased. This included soil testing for soil nutrient management, improved crop cultivars, and integrated pest, disease and weed management, which all operate to maximize the benefit of improved soil moisture status. In Bundelkhand, mechanization in agriculture is not widely practiced and therefore, needs-based mechanization interventions, such as use of zero-tillage and laser land leveler, were also introduced. This has reduced labour and the energy cost of irrigation application, and also enhanced water use efficiency. Moreover, use of a zero-tillage, multi-crop planter helped reduce seed quantity use and the cost of cultivation, as well as encouraging line sowing, and most importantly encouraged better utilization of residue soil moisture available in the surface soil layer. More than 250 farmer participatory demonstrations, on various best management practices, were undertaken to support the capacity of farmers to adopt improved technologies.

Box 1: Renovation of *havelis*: bringing a lost tradition to life

Between the 10th and 13th century, the Chandela dynasty of Bundelkhand region took keen interest in conserving water as a means of supporting livelihoods and the development of the region. To address water scarcity and recharge groundwater, they established a network of several hundred tanks, called *havelis*. These structures were constructed in a toposequence, with 50-100 meter earthen embankments, 5-8 meters wide, in such a way that they harvest surface runoff (Shah, 2003; NITI Aayog, 2016).

Almost every village in Bundelkhand has, for a long time, had a traditional *haveli* rainwater harvesting tank system. *Havelis* were built 2-3 meters high, across the stream network, depending on the catchment area. Runoff generated from the catchment is harvested during the monsoon and used for multiple purposes by the village community. This facilitates groundwater recharge, harvests rainwater, and also provides water for supplemental irrigation in nearby fields. Once the monsoon recedes, the impounded rainwater is drained out and the tank area prepared for cultivating Rabi crops, using the residual soil moisture. Traditionally, the community periodically took care of the maintenance of tank bunds, de-silting, repair of water outlets, and scheduling of water releases. Water drained from *haveli* tanks was used by downstream farmers for pre-sown irrigation, and surplus water was released through the drainage network. The productivity of *haveli* fields is 15-25% higher in general than nearby fields, due to the deposited silt and organic matter (Sahu et al., 2015). The *haveli* system of cultivation is an excellent example of participatory rainwater management and collective action for the management of available natural resources in Bundelkhand region.

5. Innovation process of AWM interventions in Bundelkhand region

The innovation process to intensify the rainfed dominated production system in Bundelkhand was facilitated by a range of partners focused on knowledge transfer, capacity and awareness building. National, state and local policies have clear ambitions to enhance the rainfed dominated production systems of smallholder farmers in dryland areas, including Bundelkhand region. However, capacity and resources need to be pooled beyond local agricultural extension and advisory services. In addition, a clear strategy with recognition of the time it takes to achieve improved rainfed production to improve social and livelihood conditions, is needed. In the case of the mesoscale watersheds located in Bundelkhand, a partnership was built on the rich understanding of the region's issues by the National Agricultural Research System (NARS), together with international knowledge, based on ICRISAT's experience of over 40 years of watershed development. It took significant effort to generate trust and interest from local communities and village institutions. Investment came from various stakeholders, and agencies such as ICAR, company corporate social responsibility programs and state government. The community invested their time in project planning, and intervention implementation. In terms of extension, farmers in the region were not aware of improved methods of cultivation (new crop varieties, machineries, package of practices). These projects have given them the opportunity to interact with researchers of various disciplines, extension officers of both the public and private sectors, and enabled these farmers to gain first-hand knowledge on improved technologies and methods. Large scale exposure visits to learning sites have generated farmer confidence to adopt these new technologies in order to realize greater benefits. Figure 7 summarises the innovation process of AWM interventions in Bundelkhand, carried out by ICRISAT, ICAR-CAFRI and partners, from 2006 onwards.

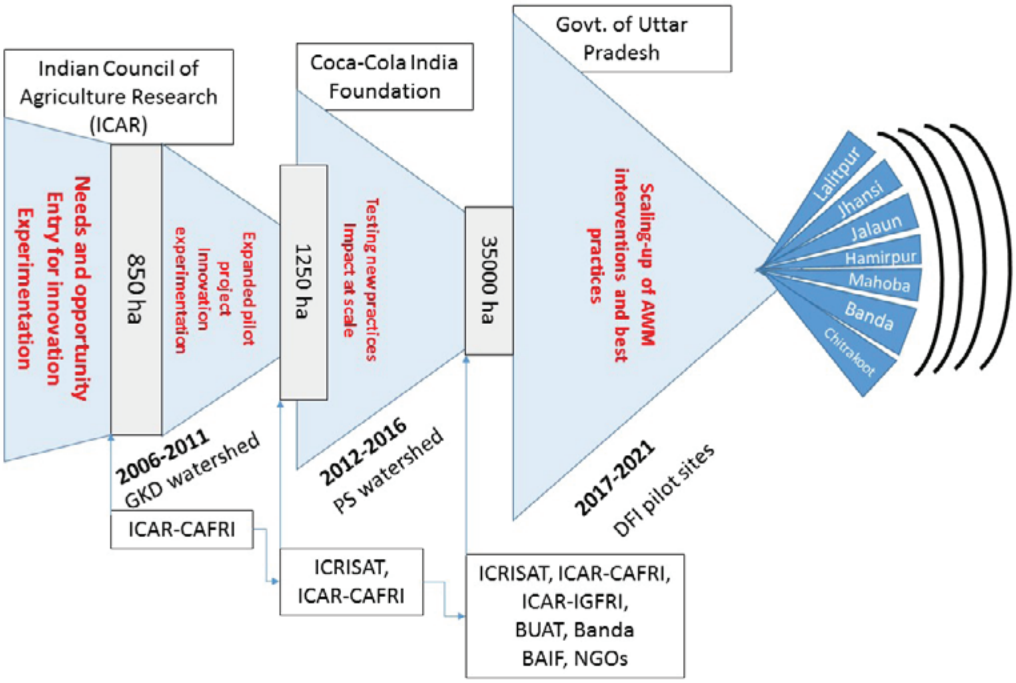

Figure 7: Scaling up pathways of AWM interventions in Bundelkhand region (Source: Authors' own compilation)

Model watersheds in Bundelkhand region

The innovation journey began in 2006 with the ICAR-CAFRI implementing interventions in the GKD watershed. This 850 ha, mesoscale watershed in the Tikamgarh district of Madhya Pradesh state was targeted. Prior to 2006, more than 30% of the area was under degraded forest, 20% was wasteland, and 40-50% was under cultivation with a poor productivity status. ICAR-CAFRI took the lead in conceptualising, designing and implementing new AWM interventions, and regenerating existing AWM solutions. The focus was on developing technically improved rainwater harvesting structures, combined with agroforestry interventions and crop management (see section 4.2), to secure and utilise rainfall better. The project was implemented between 2006 and 2011. ICAR-CAFRI designed low cost (30-40% less compared to normal structures) but robust, water harvesting structures, better suited to the watershed environment and context. Infrastructure developed in the GKD watershed, has been contributing effectively since 2006 with no maintenance. This is due to the superior quality of the structures. We envisage that these structures will continue to serve for more than 50 years. In addition, a number of low cost gully control structures were constructed along the first order streams, at upstream locations, which helped to trap silt and control land degradation. Concurrently it reduced the sedimentation load in middle and downstream check dams. The PS watershed, developed by ICRISAT-ICAR-CAFRI (2012-2016), was different from GKD in terms of land use, land cover and slope. PS has flat terrain, with less than 2-3% slope, and is largely dominated by agriculture (>90%). The major intervention here was the renovation of the defunct, traditional *haveli* system, in addition to the above mentioned structural innovations.

The following innovations were introduced in these pilot watersheds:

- The entire structure of traditional *haveli* were reinforced with new designs informed by both farmers and researchers. The principal aim was to meet rainfall, internal erosion, flood and burrowing challenges, and increase durability (section 4.1.2, Box 1)
- Check dam designs were improved to; stabilise structural strength, enhance the spillway, and prevent piping (due to seepage) around the structure.
- Collective farmer participation was fostered in the *haveli* renovation process, as submerged areas of the *haveli* belong to a number of farming families, and their consent for the renovation was important. Realizing the benefits of the *haveli* system, other farmers came forward to request renovation of other such structures for wider community benefit.

KISAN MITrA in Bundelkhand region under Doubling Farmers' Initiative

Recognising the benefits of AWM interventions, combined with best management practices, the Government of Uttar Pradesh asked ICRISAT to develop sites of learning by scaling these interventions and practices in all seven districts of Bundelkhand region. This program, which took place under the Doubling Farmers' Initiative, was called the Knowledge Intensive Sustainable Network Mission India for Transforming Agriculture (KISAN MITrA).

In May 2017, with the district administration's help (District Magistrate, Chief Development Officer, Joint Director of Agriculture, Deputy Director of Agriculture), pilot sites, covering areas of about 5000 ha area (hydrological boundary), in all seven districts were identified. Two to three villages were selected, for developing as a pilot site, in each district. The project aimed to reach 20,000 households, covering a total population of 100,000. Between May 2017 and June 2018, ICRISAT developed engagement partnerships with each community, with the help of local NGOs. Based on learning from the GKD and PS watersheds, during 2006-2016, scaling efforts were focussed on enabling water management needs to be combined with good agronomic practises in order to intensify rainfed agriculture. The process began with soil sample collection, analysis and a soil fertility management campaign. ICRISAT formed a consortium of national institutes; ICAR- CAFRI, Jhansi; ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Jhansi; Banda University of Agriculture and Technology (BUAT), Banda; Bharatiya Agro Industries Foundation (BAIF) and local Bundelkhand region NGOs.

From June 2018 onwards, four principal interventions were promoted to raise awareness of the tested best prcatsies in waterharvesting and crop managemnt, and improve rainfed cropping areas:

- Water interventions: a plan for implementing AWM interventions (*in situ* and *ex situ*) was developed with the aim of renovating existing structures (*haveli* system) and developing new *in situ* and *ex situ* water harvesting structures. These interventions created about 500,000 m^3 of storage capacity, which would facilitate groundwater recharge in about 2500 acres.

- Soil interventions: a large scale, soil fertility management campaign was undertaken through wall writings and the distribution of soil health cards. 200-250 participatory farmer field demonstrations of balanced soil nutrient management were conducted. The focus was on addressing deficiencies in soil organic matter, and on restricting micro nutrients such as Zinc, Boron and Sulphur.

- Crop and agroforestry interventions were initiated in all seven pilot sites. Nearly 70,000 pits were excavated to plant teak, lemon, guava and other fruit saplings. Local ber trees were rejuvenated through budding in 228 farmers' fields. Improved crop cultivars of sesame, green gram, black gram, wheat, chickpea, field pea, mustard and barley were evaluated every cropping season, in over 2000 farmers' fields.

- Fodder and livestock interventions were initiated in all seven pilot sites. Sorted semen technology, with a higher probability of female calf birth, was introduced. This helped to address the stray cattle menace. Improved quality feed for small ruminants was introduced to ensure better health and reduce mortality rates. Green, leguminous fodder, as a balanced diet, was also promoted.

We anticipate that these best management practices may be scaled up throughout the Bundelkhand region, including Madhya Pradesh, as a number of high level policy makers have been keenly observing and reviewing these innovations. The government further validated the impact of these interventions, through external expert agencies, to verify them and to generate positive awareness of them within state machinery.

6. Data monitoring and impact analysis

Intensive data monitoring

Watersheds GKD and PS were subject to monitoring of various biophysical, hydrological, agronomic and socio-economic parameters, on both spatial and temporal scales, during the project period. This was done to better understand the process of rainfed landscape intensification, and implications for environmental and social sustainability. Water table depth was monitored in 676 dug wells (138 in GKD and 538 in PS - including some control watersheds) on a monthly time scale. This was conducted in order to understand the impact of various AWM interventions implemented during the project period. Surface runoff was monitored at selected locations using automatic gauging stations. Changes in land use, cropping patterns, and the cost of cultivation, were also measured using household surveys and remote sensing technologies.

Data collected from intensive monitoring will be used to; (i) generate evidence in order to understand key monitoring and impact indicators, which can be used by various stakeholders, including policy makers; (ii) understand the hydrological processes, land use changes and ecosystem trade-offs; (iii) refining interventions based on the actual field, and mesoscale, data base for similar agro-ecological regions (Garg et al., 2020, submitted).

Water balance analysis

Rainfall is the only source of water which is partitioned into various water balance components; surface runoff, groundwater recharge, evapotranspiration, and soil moisture changes (Figure 8). A large portion of rainfall is stored as soil moisture, which is utilized by plants and trees, or evaporates from the soil surface. After satisfying the root zone, excess water which infiltrates from surface soils percolates into groundwater aquifers. Various *in situ* and *ex situ* AWM interventions help to enhance soil moisture availability, and facilitate shallow (up to 10-15 meters) groundwater recharge. These interventions harvest a significant amount of surface runoff, both in time and space.

Surface runoff was directly measured from gauging stations in the watersheds. Groundwater recharge was estimated based on the water table fluctuation method (Sharda et al., 2006; Dewandel et al., 2010; Glendenning and Vervoort, 2010; Garg and Wani, 2013; Singh et al., 2014). Evapotranspiration was estimated using the one dimensional water balance model for different land uses (Singh et al., 2014).

Impact of AWM interventions

Impact on water balance components

Various AWM interventions have influenced watershed hydrology and provided the basis for turning this rainfed agro-ecological system into a more productive area, for the improved wellbeing of the communities living in them. Constructed water harvesting structures have harvested surface runoff, infiltrating water for soil moisture and shallow groundwater outtake. Figure 9 compares outflow generated from the GKD watershed, and a nearby control watershed, between 2006 and 2011. Data shows that surface runoff is increasing proportional to rainfall amount. No runoff was generated at 400mm or below. Nearly 80 to 150 mm of runoff is harvested by low cost water harvesting structures from year to year. Outflow was reduced by 50%, compared to a mere 10-20%, during normal and wet years (Figure 9). Figure 10 summarizes the water balance components, and other impact indicators, of the GKD and PS watersheds, along with respective nearby control watersheds. Water balance components, measured from treated and control watersheds in both the GKD and PS watersheds, show that the various *in situ* and *ex situ* water harvesting interventions have changed hydrological processes. A portion

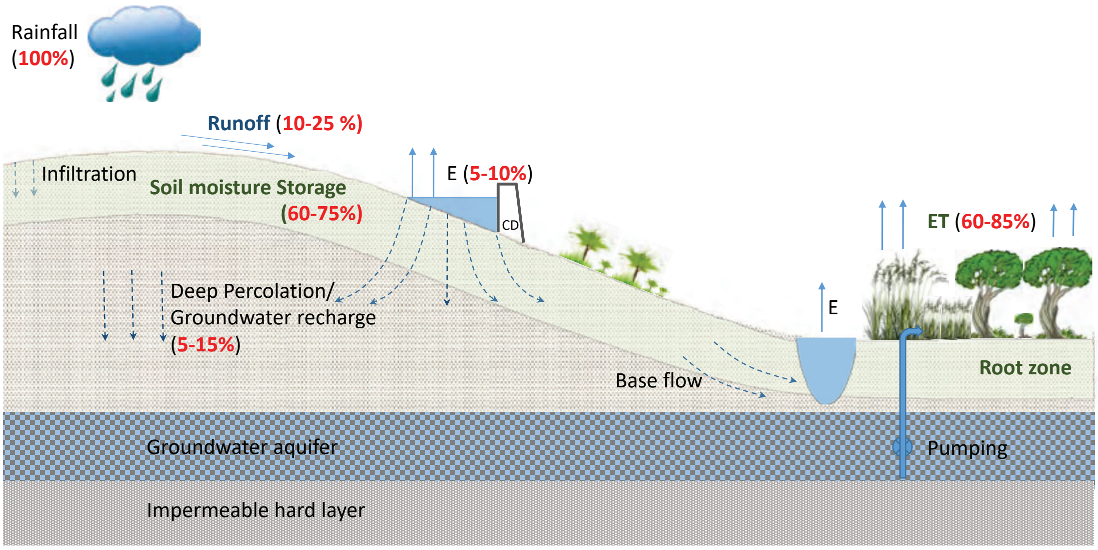

Figure 8: Hydrological processes of a mesoscale watershed in semi-arid tropics of Bundelkhand region (Source: Authors' own compilation based on primary data collection)

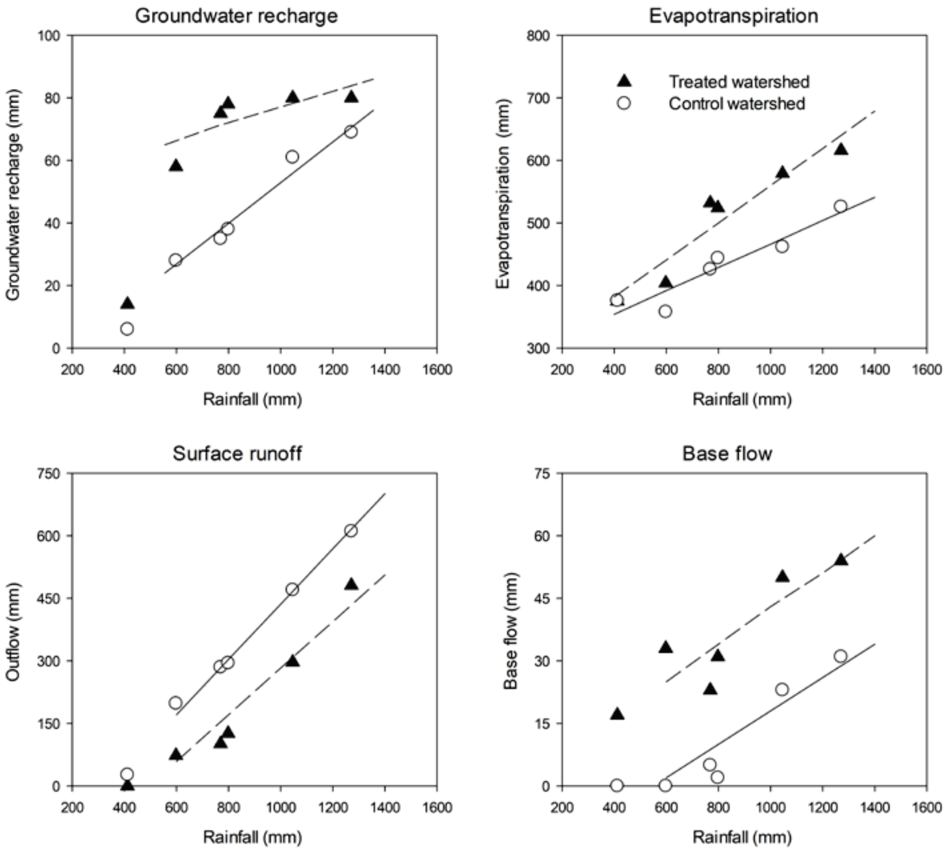

Figure 9: Comparing different water balance components of the GKD (treated), and nearby control, watersheds, between 2006 and 2011, on an annual basis. (Source: Singh et al, 2014)

of runoff, which was previously leaving the watershed, is now harvested as groundwater recharge and soil moisture.

For example, out of 850mm of rainfall in the GKD watershed, 34% (274mm) was generating runoff in the control watershed, whereas only 21% (164mm) generated runoff in the treated watershed. Groundwater recharge in the control watershed was 7% (59mm) vs 12% (96mm) in the treated watershed. Similar results were also found in the PS watershed (Figure 10). Notably, the number of days baseflow received increased from 35-42 days to 110-122 days, between the control and treated watersheds respectively.
The data also shows that the average annual soil loss has significantly reduced (2-3 times) due to various *in situ* and *ex situ* interventions. Increased groundwater availability is reflected not only in an enhanced groundwater table (2-2.5m additional pressure head), but also in the number of pumping hours (from 62-86 to 125-156 hours in the control and treated watersheds respectively). A higher number of wells are now yielding even in May, which is the hottest summer month (max temperature 42-470C) in the Bundelkhand region, improving temporal water security.
A fraction of the harvested runoff contributed to groundwater recharge. AWM interventions have made a significant impact during dry years. For example, recharge estimated in the treated watershed was 55mm, compared to 25mm in the control watershed, under 600mm rainfall conditions. Further, our analysis revealed that achieving 55mm groundwater recharge, under non-intervention conditions, required a minimum of 1000mm rainfall. The probability of receiving 1000mm of rainfall, or above, in this region is less than 30%. However, the probability of receiving 600mm of rainfall, and above, is more than 85%. Thus, AWM interventions have built drought mitigation resilience.

Increased shallow groundwater recharge also contributes to enhanced baseflow. Under control conditions, the amount of baseflow in various

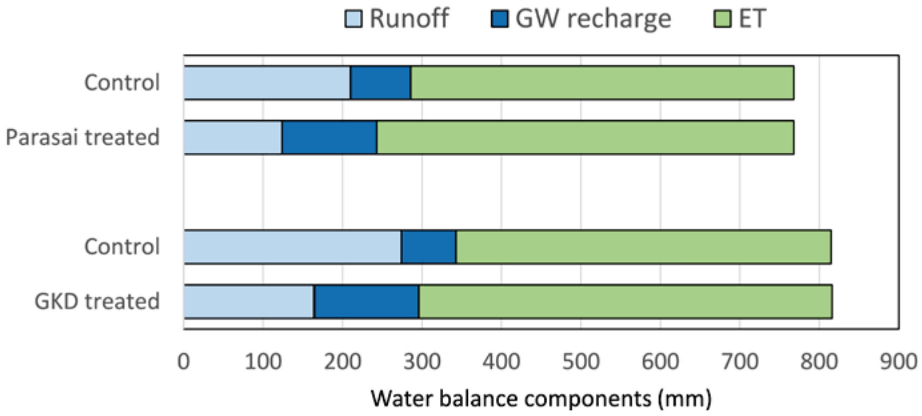

Figure 10: Water balance component of GKD (2006-2011) and PS (2012-2016) watersheds, and nearby control watersheds. (Source: Authors' own compilation based on primary data collection)

years was recorded as up to 30mm a year. Baseflow after AWM interventions increased by a minimum of 15 mm (Figure 9).

Groundwater table data, measured at GKD and a nearby control watershed for a selected year is shown along with received rainfall in Figure 11. The data is presented in terms of hydraulic head. An additional 1m head was found in dug wells of the GKD watershed throughout the year compared to the nearby control watershed, on an average basis (Figure 11). Figure 12 further shows the proportion of dug wells with different head levels in the treated and the control watersheds, before monsoon (mid-June), post monsoon (mid-October) and before the summer (mid-February). 30% of the wells were found to have less than 1m head pressure in the treated watershed, compared to 50% of wells in the control. Head pressures of 1-3m and 3-5m were found in 40% of wells in the treated watershed and 10% of wells in the control. 45% of wells had 1-3m, 20% of wells had 3-5m, and 5% of wells had >5m head pressure in the treated watershed before the onset of monsoon.

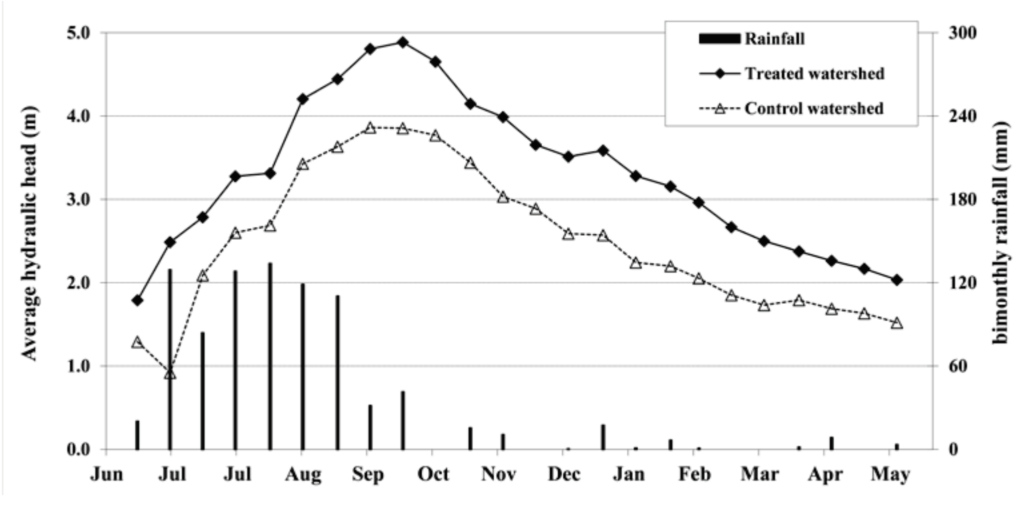

Figure 11: Average hydraulic head measured in dug wells on bimonthly scale in treated and nearby control watershed in GKD watershed ($n_{control}$=42; $n_{treated}$= 96) (Source: Authors' own compilation based on primary data collection)

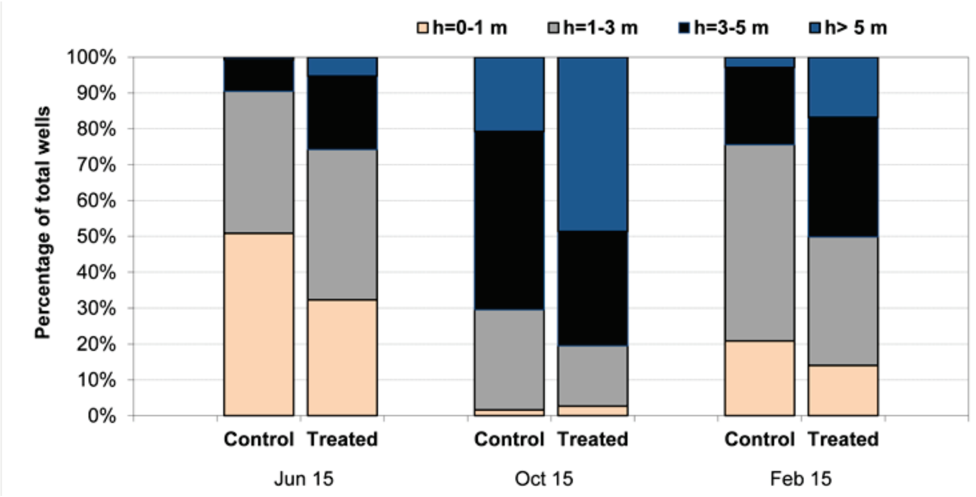

Figure 12: Status of hydraulic head in wells ($n_{control}$=42; $n_{treated}$ = 96) in different seasons, in treated and nearby control, watersheds in the GKD watershed (Source: Authors' own compilation based on primary data collection)

AWM interventions made a significant change in head pressure status in treated watersheds, as 50% of wells were found to have a head pressure of more than 5m, compared to only 20% of wells with a similar status in the control watershed, inthe month of October. Nearly 50% wells were found with head pressure of 3-5m or > 5m in the treated watershed by the end of February, compared to only 25% wells of similar head status in control watershed (Figure 12).

Crop intensification, productivity and income

With increased groundwater availability, a large amount of fallow land was converted to cultivation in the GKD watershed (Figure 13). Before these interventions, farmers left about 30% of agricultural land fallow due to water scarcity. The major of crops cultivated before the

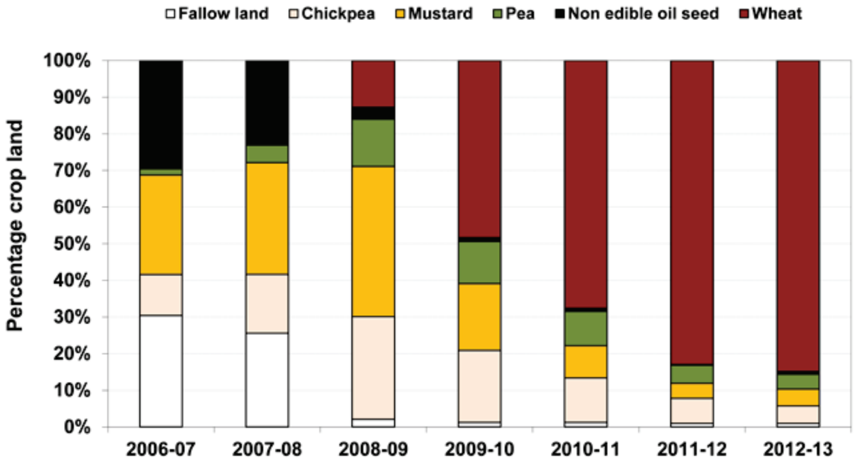

Figure 13: Change in cropping patterns in the GKD watershed, between 2006-07 and 2012-13 (Source: Authors' own compilation based on primary data collection)

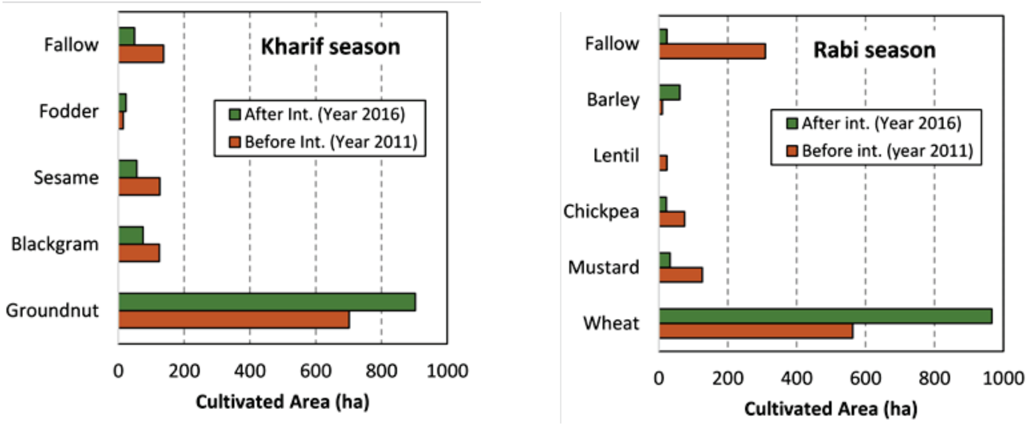

Figure 14: Change in cropped area cultivated before, and after, the watershed interventions in the PS watershed (Source: Authors' own compilation based on primary data collection)

interventions were mustard, field pea, chickpea and other non-edible oilseeds, which were largely grown under rainfed conditions, and one or two with supplemental irrigation. With increased groundwater availability, farmers shifted their crop types from low water consuming to moderately water intensive crops, such as wheat. This requires 3-4 events of supplemental irrigation to support crop development, given this has higher economic returns to the farmer, even when including the labour cost. More than 80% of total cultivable areas shifted to the cultivation of wheat, and the other 20% to other crops. This also increased dry fodder availability, supporting livestock populations.

The water harvesting interventions and productivity enhancement activities implemented in the PS watershed had a significant impact on water resource availability, incomes and farmer livelihoods. Water was no longer a scarce commodity. There was a surplus of both surface and groundwater, even at the end of summer. Hydrological monitoring showed that a minimum of 250,000m^3 of water was harvested in storage structures, which enhanced groundwater levels by 2-5m, with an average of 2.5m compared to the baseline. These rainfed system interventions have significantly changed cropping patterns in both the *Kharif* and *Rabi* seasons (Figure 14).

With increased water availability, the cost of cultivation, especially of wheat and barley, has fallen. Prior to the project interventions, farmers would engage hired or family labour for irrigation due to the poor availability and low levels of

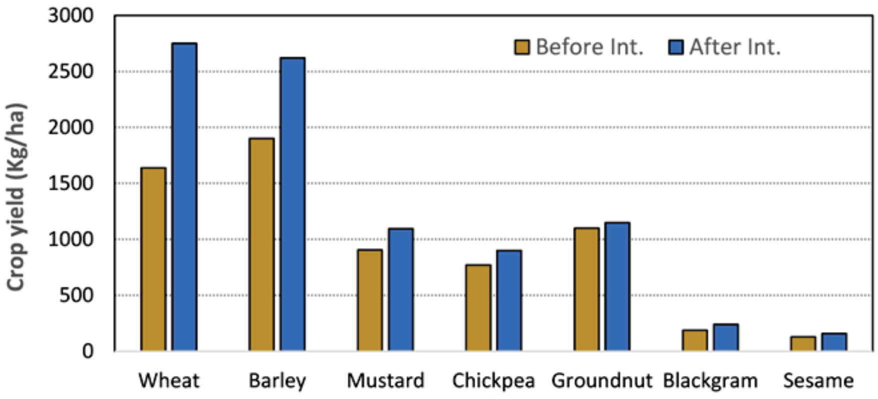

Figure 15: A comparison of the yields of different Kharif and Rabi crops before and after watershed interventions (Source: Authors' own compilation based on primary data collection)

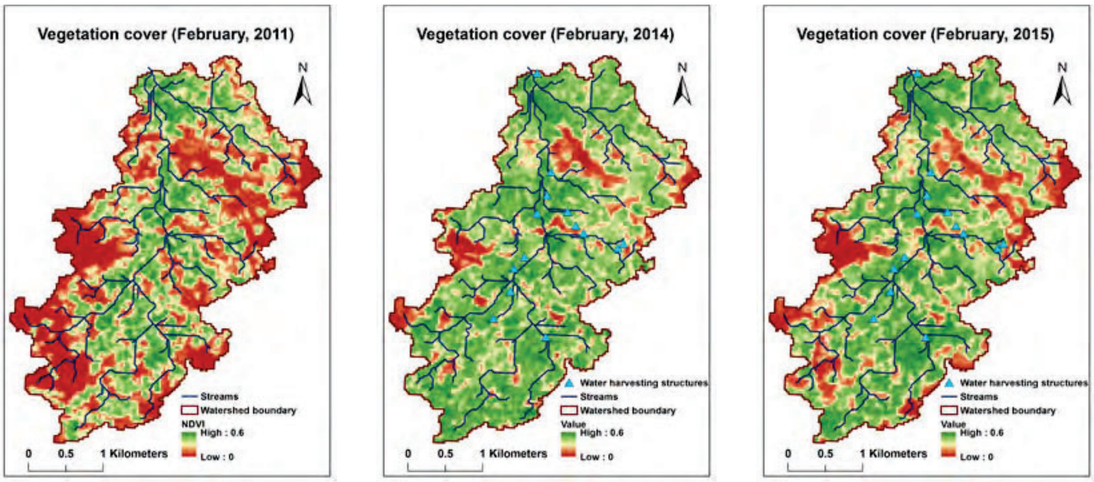

Figure 16: NDVI mapping from remote sensing in February shows Rabi crop areas in the PS watershed before (2011), and after (2014 and 2015), the interventions. Rainfall: 2010-11: 1190 mm; 2013-14: 1270 mm; 2014-15: 520 mm. (Source: Authors' own compilation based on remote sensing analysis)

groundwater needing high labour input. Water in open wells would become depleted within 2-3 hours of pumping. Project interventions saw a 2-5m increase in the water table in open wells, helping farmers complete irrigation quicker as they could pump water for 8-10 hours per day, thereby enhancing labour-use efficiency. By introducing improved cultivars and management practices, wheat yields increased from 1.7 t ha^{-1} to 2.7 t ha^{-1} (Figure 15), compounding net profit from agricultural production significantly. Wheat is a staple food for the majority of the population in Bundelkhand region. Increased wheat production not only enhances net household income, but also addresses household food insecurity. Yield and household data collected from the pilot villages clearly demonstrated that the agriculture sector alone contributed to enhancing net incomes, from 0.41 million USD y^{-1} to 1.14 million USD year^{-1} across the entire watershed (Table 4). This increased net income strengthens the socio-economic and nutritional security status of households.

Table 4: Project impact on average household incomes before and after interventions. (Source: Authors' own compilation based on primary data collection.)

Description	**Before**	**After**
Kharif area under cultivation (ha)	968	1057
Net income generated in *Kharif* (in million USD)	0.26	0.38
Rabi area under cultivation (ha)	797	1083
Net income generated in *Rabi* (in million USD)	**0.0**	**0.35**
Total net income from agriculture (in million USD)	0.26	0.73
Buffalo population	950	1300
Average milk yield (L/day/animal)	6	8.5
Annual income from livestock (in million USD)	**0.19**	**0.40**
Total net income (in million USD year^{-1})	**0.45**	**1.14**
Number of households	417	417
Average household income (USD year^{-1})	**1075**	**2725**

Note: Net income is derived by deducting cost of cultivation from gross income. Cost of cultivation includes input costs, as well as family and hired labour charges.

Normalized Difference Vegetation Index (NDVI) mapping from remote sensing in February shows Rabi crop areas in the PS watershed before (2010-11) and after (2013-14 and 2014-15) the interventions. With increased groundwater availability, a significant amount of fallow land was converted into agricultural use, which made a significant contribution to total production and incomes, by restoring the production capacity of fallow land and increasing crop productivity, (Figure 16).

The AWM interventions also improved fodder and livestock productivity as biomass was enhanced, and fodder became more available. The number of buffaloes in project villages increased from 950 to 1,300, with increased milk productivity of 2-3 l d^{-1} animal $^{-1}$. Livestock-based incomes increased from USD 0.19 million $year^{-1}$ to USD 0.40 million y^{-1}, a gain of USD 0.21 million $year^{-1}$. Altogether, average household income in the PS watershed increased from USD 1075 to USD 2725 hh^{-1} $year^{-1}$, clearly indicating the co-benefits that interventions in Bundelkhand region present (enabling a doubling of farmer incomes) (Table 4). The interventions also enhanced ecosystem services; greater greenery, more tree biomass, reduced soil erosion, and carbon sequestration. Drudgery and migration levels fell significantly in the pilot villages, with increased availability of water for agriculture and livelihood opportunities.

Empowering young professionals

It is important to develop human resources skills, including those of rural youth. This initiative recognized the opportunity to involve local youth, as young professionals working for the project and acting as ambassadors of the best management practices (BMPs) in their respective locations. These young professionals acted as catalysts, ensuring the participation of a large number of beneficiaries. In addition, the BMPs have been demonstrated in a large number of farmer fields, which has addressed two important issues: (i) building the capacity of individual farmers, (ii) dissemination of BMPs to fellow farmers with a view to scaling up. For example, laser land leveling work was initially demonstrated in a few farmer fields, after realizing the benefits (improved irrigation efficiency and reduced labour cost for irrigation application) more farmers came forward to adopt the technology. Further, a few young farmers were willing to offer this intervention as a business opportunity in which they could be service providers. We chose one or two masons from Bundelkhand districts and helped them to work at Jhansi (one of the pilot sites), in order to enhance the skills of masons to expedite scaling up. They were given hands-on training on how to construct check dams: excavation, reducing the width of the foundation, placing iron bars, constructing various components of rainwater harvesting structures, avoiding preferential flow in varied situations, and the quality of materials required. 15 masons were trained in April 2019 at Jhansi and then deputed to their respective districts to undertake water harvesting activities. Regular follow-ups and guidance were provided by the CAFRI and ICRISAT teams.

Bridging yield gaps through best management practices

A stratified soil sampling method (~25-30 ha/sample) was used to collect 1219 geo-referenced soil samples from 20 pilot villages across seven districts during March-May 2018. Analysis of the soil test results shows that farmer fields are degraded in terms of soil organic carbon (SOC) and key nutrients such as nitrogen (N), phosphorous (P), potassium (K), boron, zinc, iron and sulphur as well as pH. Low SOC levels also indicate N deficiency. Deficiencies were observed, in available P mainly in four districts, and of K in two districts. Bearing these results in mind, the cost of phosphatic and potash fertilizers can be optimized. However, there was also widespread deficiency in micro nutrients: sulphur (60-97%), zinc (27-95%), boron (12-76%), and iron (1-59%). Farmers were not aware of micronutrient deficiencies and do not replenish these nutrients. This poses a challenge in terms of realizing productivity potential.

Results from the soil health tests were shared with various stakeholders (farmers and government officers) at formal and informal meetings and

Table 5: Average crop yields (kg ha^{-1}) in various districts during the Rabi season 2018-19. Figures in parentheses are the number of crop cutting experiments undertaken (Source: Authors' own compilation based on primary data collection)

District	Chickpea	Field peas	Mustard	Wheat
Hamirpur	1900 (10)	2475 (09)	1500 (11)	3400 (11)
Banda	1230 (16)	-	1560 (16)	4150 (17)
Jalaun	2745 (8)	3150 (12)	2510 (10)	3400 (12)
Jhansi	2060 (20)	1470 (5)	710 (8)	4100 (19)
Lalitpur	1835 (11)	2100 (9)	1400 (9)	3930 (11)
Mahoba	1260 (10)	2200 (5)	1000 (8)	4400 (25)
Chitrakoot	2020 (20)	-	1400 (6)	3950 (39)

workshops. Soil health cards showing soil nutrient status and new improved, site specific fertilizer recommendations were distributed. Block-specific information on nutrient status, and fertilizer recommendations, were summarized in public displays of wall writings for wider dissemination.

Nearly 1000 farmer participatory field demonstrations were undertaken on balanced fertilizer application and improved crop cultivars of chickpea, field peas, mustard and wheat were undertaken in Bundelkhand districts during the Rabi season of 2018-19. To evaluate both the performance of different crop cultivars and the impact of best management practices, 337 crop cutting experiments were undertaken in seven districts.

Large yield variations were observed among the pilot sites (Table 5). The highest yields were obtained in chickpea (2745 kg ha^{-1}), field peas (3150 kg ha^{-1}) and mustard (2510 kg ha^{-1}) in Jalaun district. Chickpea recorded the lowest yield in Banda (1230 kg ha^{-1}) and Mahoba (1260 kg ha^{-1}). The lowest mustard yields were recorded in Jhansi and Mahoba. Degraded, shallow soils with poor water holding capacity was the main reason for low yields. Wheat is largely cultivated in a groundwater irrigated system, and grain yields

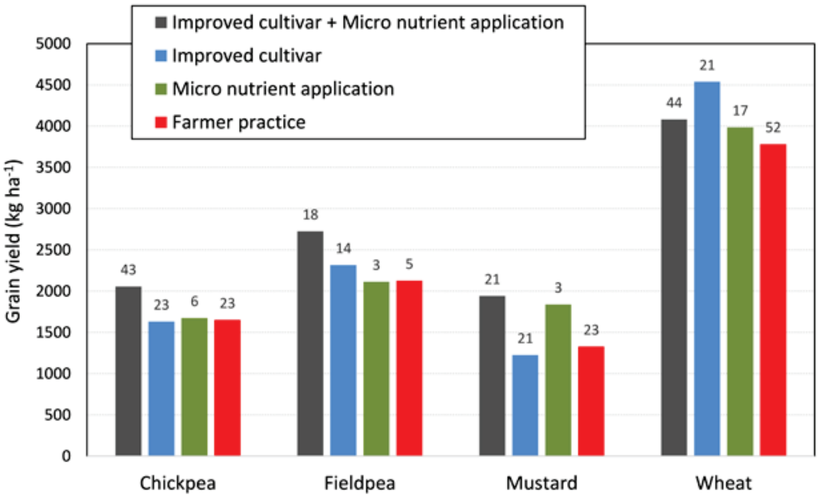

Figure 17: Impact of improved crop cultivars and micronutrient application compared to farmer practices on different Rabi crops (data compiled from all the seven districts of Bundelkhand). Values above the bars denote the number of crop cutting experiments undertaken (Source: Authors' own compilation based on primary data collection)

ranged between 3450 kg ha^{-1} and 4450 kg ha^{-1} (Table 5).

Results of crop cutting experiments were further analyzed to ascertain the performance of different cultivars. A comparison of the performance of improved chickpea cultivars JG-11 and JG-14 and local cultivars showed a superior performance of the former in most districts. JG-14 was found superior, between 250-1000 kg ha^{-1} additional gain was recorded with this cultivar in most of the districts.
Performance of JG-11 was found to be better in Lalitpur, with 500 kg ha^{-1} additional yield compared to the local cultivar. Performance of field peas (Prakash variety) appreciated in all seven districts, with nearly 500 kg ha^{-1} on average additional yield recorded in the pilot sites of Hamirpur and Jalaun districts.

Improved mustard variety Rohani gave the highest yield over local cultivars in Jalaun (>3000 kg ha^{-1} vs 1900 kg ha^{-1}). Performance of Rohani in Hamirpur, Mahoba, Lalitpur and Jhansi was found to be close to the existing cultivar. Whereas in other districts (Jalaun, Banda and Chitrakoot), yield gain from Rohani ranged from 125 kg ha^{-1} to 750 kg ha^{-1}, compared to existing cultivars.

Crop cutting experiment results were further analysed across four categories: (i) improved cultivar and micronutrient application, (ii) only improved cultivar, (iii) only micronutrient application, and (iv) farmer's practice (control) (Figure 17). Grain yields from treated fields were higher than that from the control. The highest yield gain in chickpea, field peas and mustard was obtained with a combination of both improved cultivars and the application of micronutrients.

The KISAN MITrA project has benefited about 15500 households directly so far. We categorized the various AWM interventions and BMPs into eight categories, as shown in Figure 18. In this initiative a comprehensive approach was followed to mitigate risks, build resilience and generate a number of ecosystem services to achieve sustainable livelihoods.

7. Drivers of change and scaling up AWM practices

The government of Uttar Pradesh and Madhya Pradesh have made huge investments in various risk mitigating strategies for rural farming communities to enhance food and water security through a range of schemes and programs. These have helped the region expand areas under irrigation, and crop intensification of rainfed areas, as well as reducing the risk of crop failure. However, a large part of the region is still suffering from water scarcity, land degradation and poverty.

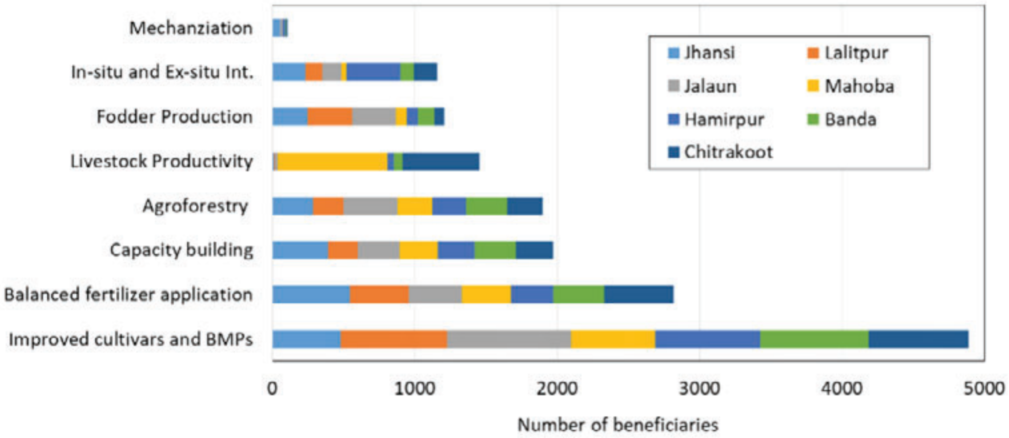

Figure 18: Distribution of beneficiaries by project intervention (May 2017 - December 2019) in KISAN MITrA project, Bundelkhand region (Source: Authors' own compilation based on primary data collection)

This therefore requires holistic, science-led solutions to mitigate risks and ensure scaling up and sustainability. Below are the drivers of change, which indicate pathways to create large-scale, system level impact.

Multi-institutional consortium

As watershed management requires multi-disciplinary expertise, a team of researchers (hydrology, engineers, soil scientists, agronomists, and GIS, socio-economic and gender experts) from ICAR-CAFRI was formed. They were involved in designing and implementing site specific interventions, with the help of local communities, in 2006 in the GKD watershed. Similarly, ICRISAT and ICAR-CAFRI formed a consortium to develop the PS watershed between 2012 and 2016. In the KISAN MITrA initiative, a multi-institutional consortium was formed, led by ICRISAT, to scale up a number of best management practices: rain water harvesting, agroforestry, productivity enhancement, mechanization, fodder production, livestock management and capacity building.

Institutional arrangements

To ensure the sustainability of interventions, community-based organizations such as village committees, self help groups, user groups and environmental clubs have been promoted in all project locations. The beneficiaries of the various interventions have been identified and intervention specific user groups were formed. To ensure effective management, these groups have been trained on the roles and responsibilities relating to maintenance of the intervention assets.

For example, farmers with block plantation of teak on field bunds have formed a user group and collect proportionate user fees for the maintenance of these trees. Similarly, village committees have been formed in all project locations. They decide on the sharing of inputs and also suggest suitable locations for various natural resource management interventions, on a year to year basis.

Promoting accountability, transparency, flexibility in operation and ownership among the community

The concept of a 'measurement book' (MB) is strictly followed. This helps to maintain accountability and transparency in the execution of engineering works. Payments are based on an actual MB, which is verified and vetted by project partners, field staff and venders. There is some flexibility in terms of planning, execution and expenditure. Normally government-led programs have predefined allocations for different components even at minor scale. However, in these projects researchers have had greater flexibility to adjust physical and financial targets as per the needs of the community. In addition, expenditure relating to a specified activity is only processed after completion.

Capacity building

Capacity building is an integral part of all these interventions. The capacity of farmers, project staff, and young professionals (including women), has been strengthened through participatory field demonstrations, field days and exposure visits. For example, both the PS and GKD watersheds have acted as sites of learning. More than 5000 farmers, policy makers and researchers have visited the watershed and learned the nuances of the interventions. During such visits, farmers themselves have shared their experiences and explained the innovation process followed in the watershed. They also highlighted the changes in their lifestyle before and after the interventions.

8. Conclusions

The Bundelkhand region of Central India has a number of challenges, however it holds many opportunities for sustainable crop intensification in the largely rainfed dominated landscape. To address both livelihood and environment goals in agricultural landscapes, this case study shows a successful approach to managing multiple interventions that can be achieved through partnership between farmers, researchers, government and private sector investors.

The traditional rainwater harvesting system was the lifeline of the Bundelkhand region. However, this has become defunct due to the failure of local institutions. Nonetheless this can be rejuvenated by following a hybrid approach, combining traditional knowledge with new innovations. Large areas of the Bundelkhand region are under permanent fallow, is waste land or has been degraded due to ravine formation. This land could be rejuvenated through various *in situ* interventions. Knowledge generating institutes, government agencies and private partners need to come together to harness such opportunities. A large number of farmers in the region are still using old cultivar varieties, which need to be replaced with climate-smart crop cultivars. International, national, state and local institutes and state agricultural universities need to work together with development agencies, policy makers and farming communities to screen and identify suitable crop cultivars specific to each district, and even further at smaller scales. Moreover, the large knowledge gaps that exist among village communities about beneficial approaches and technologies also hold huge opportunity.

The Government of India, and the state government, is placing large emphasis on developing village institutions such as self help groups, user groups and farmer producer organizations. These institutions require technical backstopping from knowledge generating institutes in order to achieve the desired goals. There is large scope for needs-based mechanization in the region. Technologies such as laser levelling, use of zero-tillage and other sowing, intercultural and harvesting instruments, need to be introduced, along with large scale capacity building of local youth for the effective utilization of available machinery. In addition to government agencies, the involvement of private partners and service providers, can bring further synergy towards achieving scaling up targets. Agroforestry is a sustainable solution to ensure long term sustainability, and strengthen ecosystem services (controlling land degradation and carbon sequestration), without compromising the production system. This case study identifies the pathways for adopting best management practices. Significant efforts are now required to scale up these interventions, across a larger area, in order to benefit those in similar agro-ecological regions.

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