Research Article

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Rain Water Harvesting for Food and Livelihood Security: A case study from Pali, India

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Abstract: Arid zones are characterized by high evaporation, low and uneven rainfall, undulated topography, presence of salt layers at shallow depth in the soil and poor-quality ground water. Under these conditions an innovative farmer in the district of Pali in the state of Rajasthan, India explored options for farm diversification under hot-arid conditions at his farm. His motivation brought him to the ICAR-Central Arid Zone Research Institute (CAZRI), Krishi Vigyan Kendra (KVK) where he was trained in various basic aspects of rain water harvesting. KVK, Pali studied the methods and innovative ideas utilized by the farmers and the subsequent gain in yield and income by adoption of rainwater harvesting at his farm on a yearly basis. Initially he constructed a small rainwater harvesting structure by which he was able to store substantial quantities of water for longer duration. As a result of constant motivation, he constructed a concrete rainwater storage structure (40M x 40M x 3.5M) and explored further options to increase production at his farm. Also, development of goat farming, intercropping, raising fodder crops and grasses, and developing a fishery, all from the gains of water harvested from rains, gave him confidence and added to the prosperity of his farm. Presently, on farm productive activities, family labour mobilization and diversification provide him with a stable income. This experiential learning also led to new knowledge emerging from interactions among a hitherto powerful scientific hierarchy and served as role model for other farmers' adoption of innovative techniques.

Keywords: Rainwater harvesting; Diversification; Hot arid conditions; Role model

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1 Introduction

The most alarming challenge faced in this century is food and nutritional security and it will be a challenge for all of us, as to how to feed an additional 3 billion people by 2050. About 95% of this population growth will occur in underdeveloped or developing nations where agriculture contributes to a major portion of the per capita income. The majority, or two thirds, of the poorest people in the world are found among the 1.1 billion farmers who make their living from agriculture (Rockström 2002). The United Nations Environment Program (UNEP, 2014) estimates that more than two billion people will live under conditions of high water stress by 2050, which would be a limiting factor for development in many countries around the world (Sekar and Randhir 2007). Thus, the real game changer is water and the main concentration should be on upgrading rain-fed/dry land agriculture for small and marginal farmers in areas facing climatic variations in terms of rains and frequent floods. Excessive water loss in smallholder farming areas reduces water availability and leads to loss of valuable nutrients from top soil (Biazin et al. 2012). In addition, in dry zones most of the rainfall is received in one or two spells, hence the major portion of the rains goes to waste and is never kept as storage water for future use. Dry areas suffer not only from limited rainfall but also 'natural leakage' - 90% of rainwater is lost directly or indirectly and is unavailable for agriculture or domestic use.

India is on the edge of an unprecedented water crisis. According to a World Resources Institute estimate, in 15 years, the national supply of water is expected to fall to 50 per cent below demand, while according to the Central Water Commission, the demand for water will climb from 634 billion cubic metres (BCM) to 1,093 BCM in 2025 and to 1,447 BCM by 2050. In many of the dry arid zones the total rainfall has reduced and dry spells have increased (New et al. 2006). Water is the main factor limiting agricultural production in the hot and dry summer period of semi-arid regions. Basically, for sustainable development and food security, the key input deciding social fate is water, (Dile et al. 2013).

Water harvesting is a low-cost, easy-to-use, environmentally friendly way to recover a large part of this lost water. In-situ rain water harvesting, involves the use of methods that increase the amount of water stored in the soil profile by trapping or holding the rain where it falls, and it involves small movements of rainwater as surface runoff, in order to concentrate the water where it is required (Fowe et al. 2015). Harvesting of water maintains moisture in soil and drastically reduces run-away water. This results in enhanced productivity and ensures livelihood security among villagers. These improve the sun surface moisture content (Ngigi et al. 2005). Due to sudden and very quick loss of water collected through RWH due to evapotranspiration there has been increased focus and application of different in-*situ* rainwater harvesting mechanisms that enhance infiltration and water storage in the soil layers underneath (World Bank, 2006). It is important to note that degraded land rehabilitation and its moisture retention can also be managed through RWH (FAO, 2011). In-situ rainwater harvesting can delay moisture stress in major crops with enhanced fertility, moisture and yields (Alemu and Kidane 2014; Kidane 2014; Kidane et al. 2012; Henslley et al. 2000; Rockström 2002).

A major cause of low production in arid zones is marginal and erratic rainfall exacerbated by high runoff and evapo-transpiration losses. In-field RWH techniques have been very instrumental in overcoming this crucial period. They also reduce nutrient loss from the fields by controlling leaching losses and managing soil erosion (McHugh et al. 2007; Gebreegziabher et al. 2009). Water can be stored in artificial constructions, in surface reservoirs (ponds, dug-outs, artificial reservoirs) and in the sub-surface as soil moisture or groundwater. Soil moisture conservation (recharge of shallow aquifers) is the key to high productivity hence; RWH is the most efficient tool for boosting the soil moisture in water deficit zones (Ngigi 2003).

All this has resulted in perennial food shortages due to insufficient rainfall, which causes poor yields. It is becoming increasingly clear that, to face the food challenge over the coming 50 years, combined efforts of developing climate smart rainfed and irrigated agriculture will be required (Rockström 2002). The urgent requirement is to standardize Rainwater harvesting (RWH) techniques so as to increase water productivity in rain-fed agriculture for increased yield and productivity. Runoff generation criteria yields two types of systems i.e. runoff-based systems (runoff concentrated from a catchment) and in-situ water conservation (rainfall conserved where it falls). There are different terms for rainwater harvesting in different parts of world but the functional aspects of all is one and the same (Oweis 2004). Mati et al. (2006) defined RWH as the deliberate collection of rainwater from a surface known as a catchment and its storage in physical structures or within the soil profile.

In simple terms, rainwater harvesting is a widely used term covering all those techniques whereby rain is intercepted and used “close” to where it first reaches the earth (Hatibu and Mahoo 2000). Rainwater harvesting is a well-established practice in many parts of the world and when applied in the right environment it can provide a convenient, inexpensive and sustainable source of water. In principle, rainwater harvesting is a simple low-cost technique which requires little specific expertise or knowledge and indeed it offers many potential benefits (Otti and Ezenwaji 2013). This case study narrates the determination and hard work of an illiterate farmer to convert ten hectares of non-fertile and unusable land into an oasis consisting of different crops and fruit plants with the intervention of Rainwater harvesting. It also presents current rainwater harvesting practices in the smallholder farming areas located in the arid zone of Rajasthan India and other options for optimising rainwater harvesting to combat poverty and ensuring food security.

2 Problem Statement

A visit to Taju Khan ten hectare farm, some twenty five kilometres away from Pali in Paderly village (Figure 1), is the living portrait of a success farmer without any background in agriculture, who through his persistent experimentation and research was able to apply principles of rainwater harvesting in his farm. This led to the transformation of a barren piece of land into a role model of rainwater harvesting for other farmers of his locality.

The farm is now full of vegetation, tall green Napier grass, Ber (*Zyzyphus mauritiana* Lamk) fruits, winter season (*rabi*) crops and *Prosopis cineria*. The land was once a fallow land devoid of water. The one locally constructed and one concrete structure in the farm is now full of water. The Taju Khan field lies in Paderly Turkian village of Pali district, which is part of the Transitional Plain of the Luni Basin region. Geographically it is situated in the narrow rift of the Aravali ranges and the arid western zone. This zone is characterized by a semi-arid climate receiving rains of 300 to 500 mm annually. Luni is the only river flowing in the monsoon season in this zone. The western part of this region is mostly sandy and productive due to number of small tributaries. The main crops in this zone includes sorghum, pearl millet, maize,

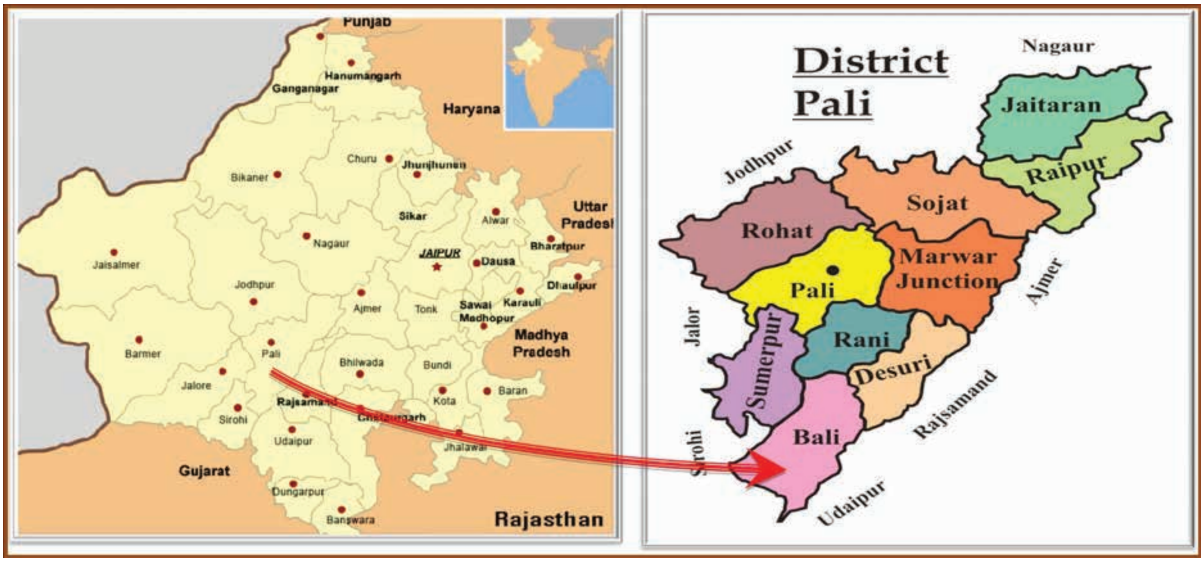

Figure 1: Location of case study

clusterbean, sesame and pulses during the rains. In the winter season wheat, barley and mustard are the main crops, in the areas having irrigation facilities. The soil type is *Typic Camborthids* (Map Unit 129).

The farmer was having 10 Hectares of land which was barren and covered with wild prosopis growing here and there. The soil was undulating having salinity of Ec 3.4-4.0 ds/m with high pH (8-9) and very low carbon content. Due to the soil structure there was a hard soil pan (5-10 cm) bellow the top soil, further making it difficult to grow any crop. The water table was very low and the quality of water was poor having pH of 8-10 further inhibiting the use of this water for irrigation.

> Taju Khan says "My basic motto in doing this was to harvest the waste going water from my area which is sufficient and surplus for my crops if properly harvested. In my case it was very easy because of the hard subsoil structures and the location of the farm on lower side of village. I utilize every drop of water by harvesting and preventing evaporation losses by mulching". "Even keeping a record of slopes and depressions can help you to go for a better harvest of the rain water says Taju khan". He is having the complete record of rains, soil profile, ground depressions, vegetation cover, grasses and the intensity of heat and sunshine for the last 16 years ever since he is managing the farm. Vegetation cover near the water resources is very crucial as it reduces the evaporation losses during peak summers which are great in arid and semi arid zones.

3 Material and methods

The event of how an unfertile and degraded patch of land was transformed into a fertile ecotype dates back to year 2000 when Taju Khan's father handed him this ancestral land, which was in a barren condition with poor soil and moisture condition and a hard murad soil underneath. After seeing the father's frustration, Taju Khan stepped in and decided to engage the farm himself. Taju Khan took it up as a challenge to solve the water scarcity issue and improve the soil characteristics of the land. He travelled to many places in the Pali district and other parts of Rajasthan in search of solutions and the only solution he was offered was that of rainwater harvesting and mulching, which had been successfully used at places with similar conditions. He began experimenting and practicing vegetation mulch in crops. It all started when Taju Khan approached ICAR-CAZRI, KVK, for help to guide him for improvement of soil and water conditions on his farm and found that a lack of water management was the main reason for the poor performance of his farm. He was given primary training on soil and water management by KVK. The field was devoid to fertile soil and was dominated by pebbles making it difficult to grow crops. The land was completely naked, devoid of any tree or vegetation cover, with some shrubs and xerophytes. He followed the basic principles of water collection and started construction of different rainwater harvesting (RWH) structures.

Taju Khan, with the help and technical guidance of KVK Pali, also established an orchard having early mid and late maturing varieties of ber. Besides the orchard, Taju Khan's farm also had an animal shed where he houses local breeds of cows and Marwari goats, helping his farm by providing manure and thus maintaining its fertility. He grows *kharif* (rainy season) crops on the rains received during rainy season and *rabi* (winter season) crops on conserved moisture supplemented with water stored from rainwater harvesting using a diesel generator set. The yield from his farm now includes wheat, mustard, chickpea, sesame and green gram ber fruits, fishes, besides the yield of variety of other wild species that provide him a considerable amount of profit. The data were collected through personal contact with the help of a well-structured interview schedule with the farmer and family members. Further they were verified by the yield, expenditure and return register of the farmer every year. The gathered data were processed, tabulated, classified and analysed in terms of mean percent score in the light of objectives of the study.

4 Results and discussion

4.1 Construction of a Rainwater Harvesting Structure

As per expert's advice and with his past experience he constructed a temporary rainwater harvesting structure at the lower side of his fields. Fortunately, this was also the passage for natural drainage of excess water from the entire nearby area. With the help of heavy-duty machines in the dry season he further deepened and widened the natural depression (Figure 4). He started with initially deepening the already low-lying area and further enlarged it. On getting initial success in subsequent years he expanded this structure into a huge pond with enough capacity to collect run-off water from about 40-65 hectares. It has a capacity of 1000 cubic metres. As a result of constant encouragement, he further designed a concrete rainwater storage structure (40M x 40M x 3.5M). The other idea he started implementing was to dig pits and deep trenches throughout his field so that the trapped water can be collected and diverted into a single source. Figure 3 shows the annual rainfall received during last fifteen years. This rainfall was sufficient for all field activities of Taju Khan's farm, provided it can be stored in soil and some structures. He constructed channels to divert the water to one place. Further, he followed strip cultivation practices in which he made ridges and furrow and thus he could trap the all the water in his field. In his orchard he made circular catchments around the trees and thus he could harvest all the water in his orchard.

5 Crops production and productivity

The crops grown on Mr Taju Khan's farm were assessed and their productivity was analysed since the area of each

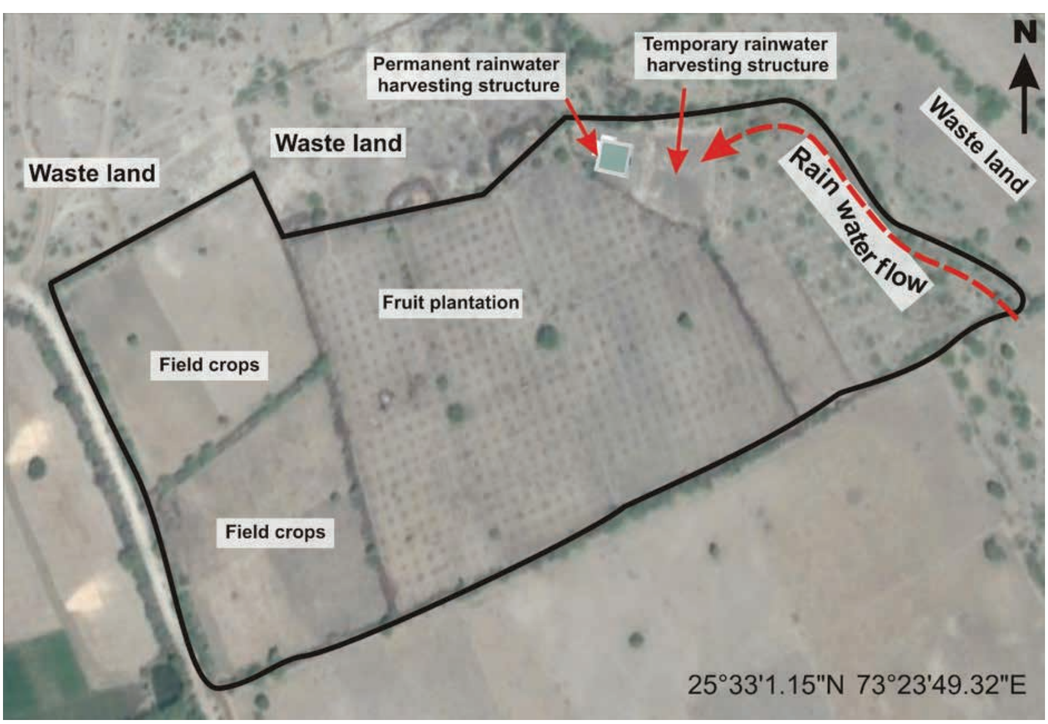

Figure 2: Satellite view of Taju Khan's field

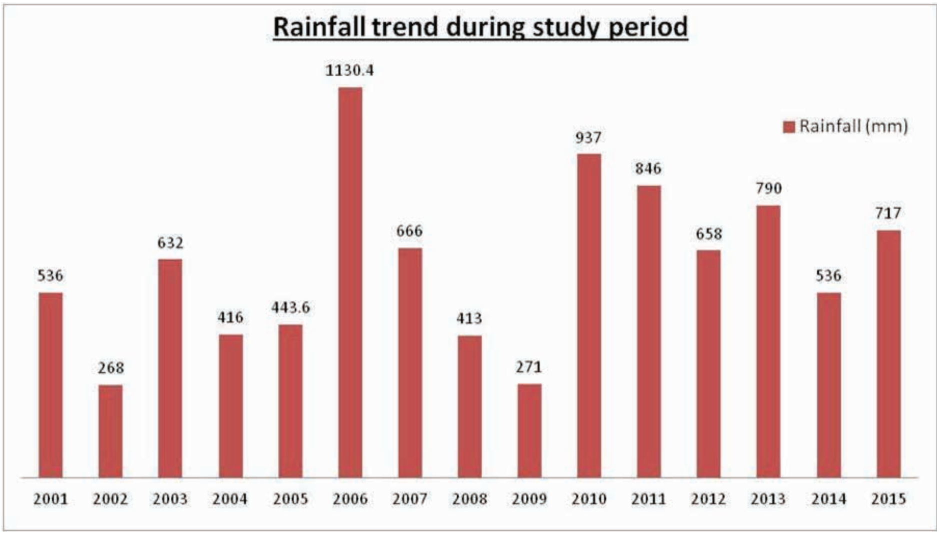

Figure 3: Rainfall trend during the study period

crop continually changes. The production economics were calculated to assess the practical utility and applicability of a RWH system. From a start where there was no production, the results (Table 1) showed that, due to rainwater harvesting (RWH) practices, the rainy as well as the winter season crops showed an increase in growth and yield in subsequent years. In the block years 2001-2005 to block year 2011-2015 there was a per hectare increase of 370 kg in wheat, 240 kg in mustard, 250 kg in chickpea, 230 kg in green gram and 268 kg in sesame was observed. The benefit cost ratio due to RWH practices ranged from 2.0-2.5 in wheat, 2.4-2.7 in mustard, 2.8-3.3 in chickpea, 2.7-2.9 in green gram and 2.4-2.5 in sesame This is because the water cycle loop is closed, shorter and thus more efficient. The farmer used the principals of zero tillage, crop rotation and mulching. RWH promotes and secures crop growth at the time of rain failure and supports crop production even during hard times (Tesfay 2011; Amha 2006). This fact is further strengthened by the results from Northern Ethiopia where sorghum production doubled by supplementary irrigation with rainwater harvesting. Similarly, the production level of peppers was also increased by up to four hundred percent through RWH techniques (Alamerew et al. 2002). In Ethiopia, Alemie et al. (2005) also reported 20, 10 and 12 thousand kg/ha yield of tomatoes, peppers and onions respectively, through adoption of RWH technologies.

Table 1: Productivity and economics of different crops cultivated

Crop	Year	Productivity (Kg/ha)	Gross cost (INR/ha)	Gross return (INR/ha)	B:C ratio
Wheat	2001-2005	4150	16500	35700	2.2
	2006-2010	4260	18500	39300	2.0
	2011-2015	4520	18200	45510	2.5
Mustard	2001-2005	1650	16600	45600	2.7
	2006-2010	1570	18700	48922	2.6
	2011-2015	1890	20470	49840	2.4
Chickpea	2001-2005	1670	12300	40800	3.3
	2006-2010	1489	13500	39900	2.9
	2011-2015	1920	15610	44850	2.8
Green gram	2001-2005	1030	11697	31200	2.7
	2006-2010	1130	12230	35900	2.9
	2011-2015	1260	13300	39500	2.9
Sesame	2001-2005	622	17500	42300	2.4
	2006-2010	460	16045	40530	2.5
	2011-2015	890	18140	43940	2.4

Figure 4: Different steps in creation of a viable RWH

Another reason for increases in yield was the unique sowing pattern and crop geometry of the farmer. Mr. Taju Khan practiced deep summer ploughing and sowing was done in a strip pattern with ridges and contours for in-situ water harvesting and retaining soil moisture.

6 Fruit production and productivity

Data presented in Table 2 shows the production and economics of the ber fruits produced during the last fifteen years. The data depicts a gradual increase in the production and productivity of all the three varieties of ber planted at Mr. Taju Khan's farm. The ber plantation started with 17 plants and today the farmer has 750 plants, all in full production. He planted three varieties, as these are early, mid and late maturing varieties. By these plantings he can get fruits from December till the end of March. Thus, he can cope with the season glut and ensure regular income throughout the entire season. The production trends showed an increase of in Gola, Seb and Umran varieties of ber due to circular rainwater harvesting structures constructed around the plants (Figure 5). The circular catchments had a radius of 1.5 metres having inner slope, which ensured sufficient harvesting of rainwater in the root zone of the ber plants. Increased moisture during the active period also increased the microbial activities, organic matter and made available other micronutrients, which further boosted production of the fruits. The fact was further confirmed by the visual observations of change in the soil colour from a dark yellow to a pale brown, increase in number of earthworms, increase in moisture content of the soil and a further increase in growth and productivity of crops every succeeding year.

Similar rain water circular catchments have also been analysed in Pakistan and the results revealed that water productivity of Grape Fruit, China Lemon, Sweet Lime, Blood red and Phalsa were enhanced up to 13%, 13%, 18%, 18% and 10% by negarims compared with semi-circles while in olives, semi-circles increased water productivity by up to 19% . Further, these practices enhanced nutrient use efficiency by conserving the soil and water. Increment in the annual income of the farmer through this strategy has encouraged the local community to adopt this practice and it became the success story in the area (Rehman et al. 2014). Kabore and Reij (2004) also concluded that the overall mean moisture content in the plots with micro-catchments was 31% higher in the wet season and 24% higher during the dry season, compared with that for plots without micro-catchments.

7 Ground water recharge

As the result of RWH the ground water has recharged to a greater extent. Initially Mr. Taju Khan had one open well, which dried up in winter, but due to RWH measures the water table increased (from 60 M to 35M) considerably with improvement in water quality. Now the water in his well never ends and he can run his diesel generator continuously for six hours for extraction of water. Moreover, there has been a remarkable improvement in water quality. Its pH reduced from 8.2 to 7.4 and Ec from 12.5 to 1.2 respectively.

Water harvesting in the drylands can provide substantial quantities of ground water recharging. Israel, for example, has expanded its water supply by some 7% by capturing rainwater and utilizing it for irrigation in arid and semi-arid regions (Tal 2006). The effect of water har-

Table 2: Ber production and economics analysis

Ber variety	Years	Production (Kg/plant)	Gross cost (INR/ha)	Gross return (INR/ha)	B:C ratio
Gola	2001-2005	38.6	18890	73430	3.9
	2006-2010	44.8	19760	74600	3.7
	2011-2015	52.2	19320	76400	3.9
Seb	2001-2005	37.5	18590	73400	3.9
	2006-2010	42.6	18980	70900	3.7
	2011-2015	53.2	20450	77200	3.8
Umran	2001-2005	42.9	17766	71500	4.0
	2006-2010	49.5	20578	76070	3.6
	2011-2015	55.7	18050	78690	4.3

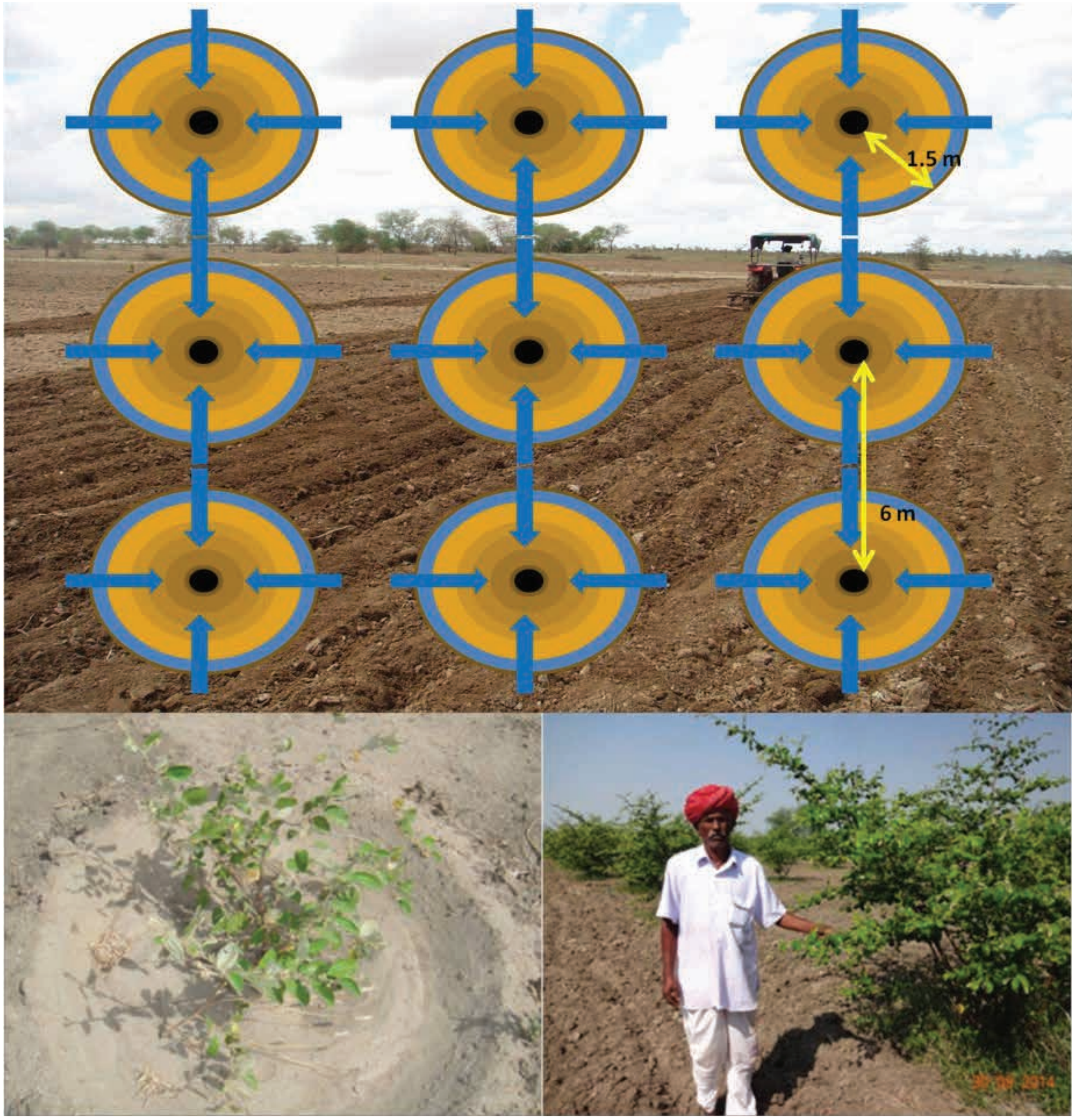

Figure 5: Circular water catchment in Ber

vesting structures on groundwater recharge and water quality, evaluated in a watershed situated in a semi-arid region in Andhra Pradesh, India, showed that the threshold value of rainfall for ensuring a 1 mm recharge potential is 61 mm. Water quality analysis revealed that except for pH, all other water quality parameters, like electrical conductivity, sodium adsorption ratio, residual sodium carbonate, total hardness, nitrate and fluoride content, reached desirable limits in close vicinity (<100 m) to water harvesting structures (Adhikari et al. 2013).

8 Net farm income and livelihood security

Mr. Taju Khan started from an income of INR 20,000 per annum, which was from rainfed agriculture crops only, because he could only grow rainy season crops, to an income of 6,15,000 in year 2015, with the adoption of RWH technologies. The soil, as well as water conditions, started improving and crop productivity also improved. With the in-situ circular catchments he started a side income from his ber orchards. He also enlarged the farm by planting 760 more ber plants with a total yield of 40 tonnes from the ber orchard.

With further refinement he started other ventures like planting of fodder plants and Napier grass, intercropping, fish farming, promoting orchard and pulse crops. The graph (Figure 6) shows a steady increase in income from the different innovations the farmer adopted with different RWH techniques, except in 2009 which was a famine year. With time, the soil structure also improved with an increase in soil fertility and a decrease in soil salinity, leading to an increase in yields and net income.

Presently on Taju Khan's farm, productive RWH activities, family labour mobilization, and crop diversification contributes to a stable and lasting economic and family-based enterprise. The findings of the present case study are also in accordance with the findings of Singh et al. (2013) who concluded that farmers' levels of interest is the main criteria for a successful farmer. Thus, the case study clearly illustrates the importance of RWH for Indian farmers in arid and semiarid zones and that a combination of agriculture along with other enterprises may be the key to a sustainable livelihood. Labour intensive practices such as in-situ RWH, manuring, limited tillage, ridging, terracing, composting organic matter and recycling plant products into the productive process, enhances soil conservation and fertility (Dile et al. 2013).

We must value the multiple functions of farms in the Third World if we are to achieve sustainable agriculture. According to the Food and Agriculture Organization (FAO, 2011) of the United Nations to face the current challenges of agriculture, we need to address agriculture and land in a broader context by integrating multiple roles. This experiential learning also led to new knowledge emerging from healthier and more equal interactions among hitherto powerful scientific hierarchies and framed learning as a social process of reflection and analysis. Now Mr. Taju Khan is also motivating others to adopt his path. Such innovations create an innovative culture in rural communities and encourages them to invest their innovation in their natural resources rather than depleting them for short-term market gain. Most of the future growth in crop production in developing countries is likely to come from intensification, with irrigation playing an increasingly strategic role (FAO, 2011). For better production and high productivity, the most critical input is access to quality irrigation facilities (Postel 2003). Irrigation has direct benefits in terms of net income and productivity (Gleick 2002). Besides yield gain, RWH supports life-saving irrigation at desired times and thus combats climatic hazards (Ngigi et al. 2005).

Rainwater-harvesting agriculture is a specialized form of rainfed farming that has a significant potential to increase food production in arid zones. RWH is a promising technology as proved by many researchers (Contreras 2013; Dile et al. 2013; Zingiro et al. 2014; Zhou 2015). Firstly, applying RWH increased the crop yield of rice (Hatibu et al. 2006; Ariyanto et al. 2016a); millet (Tabor 1995), onion, wheat, and potato (Teshome et al. 2010; Hu et al. 2014), corn (Yuan et al. 2003) and other crops by overcoming drought with supplemental irrigation. Secondly, RWH enables farmers to cultivate high-value crops with very significant associated improvements in income and livelihood (Senkondo et al. 2004; Ngigi et al. 2005). Teshome et al. (2010) showed that RWH system made it possible to harvest onion instead of previously planted crops, thus increasing the family income by many folds. In India, RWH increased farmers' incomes in different

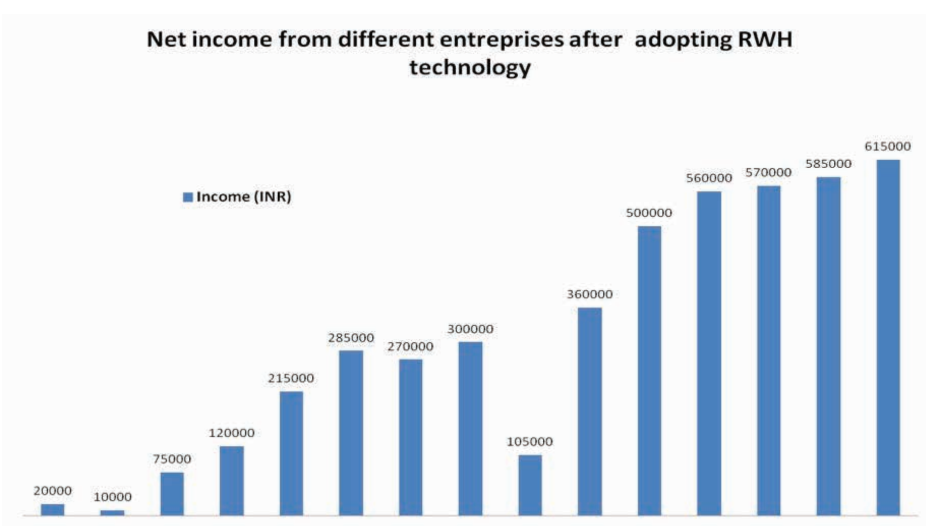

Figure 6: Net income of farmer from different enterprises

climatic zones in arid and semi-arid zones (Kumar et al. 2016).

9 Conclusions and recommendations

To date, location specific RWH is the key to overcoming major challenges of low productivity, soil degradation; high climate variability and food insecurity. RWH has been implemented in many arid and semi-arid parts of India; however, the adoption of the technology was not very fast. Sustaining and recharging the groundwater is very important. The sustainability of RWH techniques largely depends on the primary users, who are farmers, especially in low moisture conditions. Experiences with RWH throughout the world show enhanced soil moisture, recharged ground water, reduced runoff and increased crop yield, thus ensuring nutritional and livelihood security for farmers. The efficient management of RWH techniques and concern about judicious utilisation of water resources extend beyond rain fed farming; therefore, RWH have eminent potential to mitigating climatic risks in the dry Zones. Water harvesting holds its strength when it is assembled with other management practices such as tillage, nutrient management, weeding, time of sowing and crop cycles in order to increase the efficiency and intake capacity. Therefore, further on farm research and trails are needed to assess the socio-ecological and monetary impacts of RWH from a plurality of perspectives in a wide range of different localities to promote this technology in the dry zone through, improved extension services, capacity building and the promotion of farmer-led knowledge sharing. There is a need to provide training and extension services to farmers, to develop and disseminate more effective and affordable types of RWH technologies as alternatives and to design and develop alternative policy instruments and social institutions that facilitate adoption of RWH practices.

Conflict of interest: Authors declare no conflict of interest.

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