Background Paper

Preliminary assessment of a traditional approach to rainwater harvesting and artificial recharging of groundwater in Alwar district, Rajasthan

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Abstract

Farmers in the arid and semi-arid parts of northeastern Rajasthan have practiced innovative methods of harvesting rainfall runoff for agricultural purposes by building earthen embankments called *paals*. These structures are built mostly on farmer owned lands across ephemeral rivulets to collect and infiltrate water from an area of approximately 10-12 hectares. The frequent water spreads over an area of 4-5 hectares in these structures for 2- 3 months, during which it saturates the upper soil layers and seeps down to recharge groundwater. Fine sediments carried by runoff get deposited in the submerged area adding a rich layer of alluvial soil. After water infiltrates completely from the submerged area, farmers practice recession farming during *rabi* season using the soil moisture stored in rootzone layer with little or no supplementary irrigation. Groundwater recharged in paals and their surrounding areas is utilized to irrigate low water consuming crops during rabi and zaid seasons. Farmers within and surrounding this region are able to pump more water at reduced pumping costs due to raised water tables. The demand for adoption of this technology is growing rapidly and more defunct paals are being revived and more wells are being dug every year. In 1990's, several NGO's initiated programs aimed at reviving the paal system through community participation in a number of watersheds in this region. With financial and logistic support from several GO's and NGO's the technology is spreading rapidly to neighboring communities as a recognized source of water conservation for irrigation, livestock and domestic purposes during dry period. Paals are said to have led to increased cropping intensities, increased agricultural productivity and improved livelihood status among the farming community in the under-privileged districts of Rajasthan. This paper examines aspects of artificial recharging of insitu-harvested rainwater and floodwater by paals, its impact on agricultural productivity and the livelihood of the farmers in the region.

Introduction

Groundwater is the most important and significant source of water in semi-arid and arid zones of Rajasthan. Groundwater management is among the most important, least recognized and highly complex of natural resources challenges facing society. A critical question in many of the aquifer management strategies has been the optimum role for groundwater storage. In many ways the vast natural storage of groundwater systems is their most valuable strategic asset. On the other hand important components of the economic and environmental value of groundwater such as pumping costs, individual accessibility for the poor depend on the depth to water table and not on the volume in storage (Foster, et al., 2000). One of the key issues is the historical context of much groundwater resource development, which helps define major obstacles that have to be overcome.

Farming communities in Rajasthan have sought groundwater exploitation as an inevitable security against drought in areas where irrigation with surface water resources has been deficient or nonexistent. Due to frequent dry spells and unreliable surface water supply, farmers in Rajasthan have discovered several means of maximizing subsurface storage and its availability at times of need. The local inhabitants, rich in experience, have evolved their methods for efficient water resources management using rainwater-harvesting techniques. In order to store water, they raised their field boundaries to heights equaling 1-2 m to tap the rainfall runoff originating within their fields. The water stays in the field for two-three months even after monsoon. The technology directly influences water availability in the areas immediately surrounding the paal, and helps tap the runoff which would otherwise be lost to downstream or as evaporation and most importantly, controls soil erosion. The stored water infiltrates into the soil mantle and gradually percolates down to recharge the groundwater, which is extracted using open wells and tube wells for irrigating the crops during *rabi* (Nov-April) and *zaid* (April-mid-July), until the onset of monsoon. Farmers undertake cultivation of rabi crop such as mustard in the submerged area after all the water is infiltrated, utilizing the residual soil moisture. This practice of water conservation prevents soil erosion in the upstream and downstream fields from flash floods and helps maintain a stable slope for cultivation. Gradually due to community interest and efforts, this practice evolved into a large-scale phenomenon, submerging lands owned by one or more farmers. Series of such cascading paals with provsion for surplusing arrangements were constructed across the drainage path with community efforts, thus evolving a system of rainwater water harvesting. This sequentially placed cascading arrangement of paals has proven to be a perfectly designed traditional watershed management system for this region. It is estimated that there were about 3000 such Paals in Alwar district, which was the backbone of the rainfed agriculture in the area during rabi and supplementary irrigation during zaid.

Paals were part of the indigenous technology developed by the Mewats. Mewats (Meos), the original inhabitants of the region are historically considered as the warrior class and were severely neglected during colonial era after they supported the last moghul emperor in revolts against the colonists. After partition of the country, a sizable population of Meos migrated to Pakistan and their lands were redistributed to refugees and lower caste farmers, in addition to other migrants including Sikh, Punjabi and Sindhi. The immigrants were ambiguous about their stay in the regions and were unaware of the importance of paals due to which the maintenance of these indigenous structures was ignored and most of the structures eventually breached and were abandoned.

Maintenance of these structures was also affected due to subdivision of the paals that resulted from fragmentation of lands among various owners. The areas that were initially submerged under *paals* that covered about 4-6 hectares of land were severely subjected to land erosion due to breaching of paals and subsequent decrease in their productivity. It has been reported that the mustard production in the submerged area, which used to be 0.4-0.5 tonnes per hectare decreased to 0.2-0.25 tonnes per hectare in the catchment of breached structures (Singhi, 1998). An estimated 15000 hectares of cultivable land in Alwar district was degraded to half its productivity in the affected areas. With reduced recharge from defunct paals, farmers experienced drastic lowering of the watertable in their wells and in some cases drying of wells. About 11 wells in the Beda ka Bas settlement which is part of the study area were reported to have dried completely during drought years before intervention of repairs and rehabilitation.

In the early 1990s, PRADAN (Professional Assistance for Development Action), a non-governmental organisation, initiated a programme aimed at revitalising the paal system through community participation in a number of watersheds in this region. Several new paals were also built. Nowadays, field bunds are also constructed in the area between two paals along with field-leveling of bunded plots.. The combination of bunds, field-leveling and paals are said to make the overall system more effective and increase its lifetime. Increasing food demands has forced these farmers to adapt to this traditional technology and are now self-sufficient and economically progressing. The revival of these structures is an increasingly demanded technology in which several NGO's such as PRADAN, TBS and GO's are presently involved.

Discussion of the preliminary survey and analysis

The project area comprises of four micro-watersheds, amongst 10 that form part of the Khanpur Mewan macro-watershed (Figure.1). It lies in the Mewat region of Alwar district of Rajasthan (latitude: 27° 45'-27° 50' N; longitude: 76° 45'-76° 50' E). The microwatersheds comprise of three villages with several hamlets. Two ethnic communities, Meo-muslims and Chamars, a scheduled caste community form 75% of the total population (Singh, 2000).

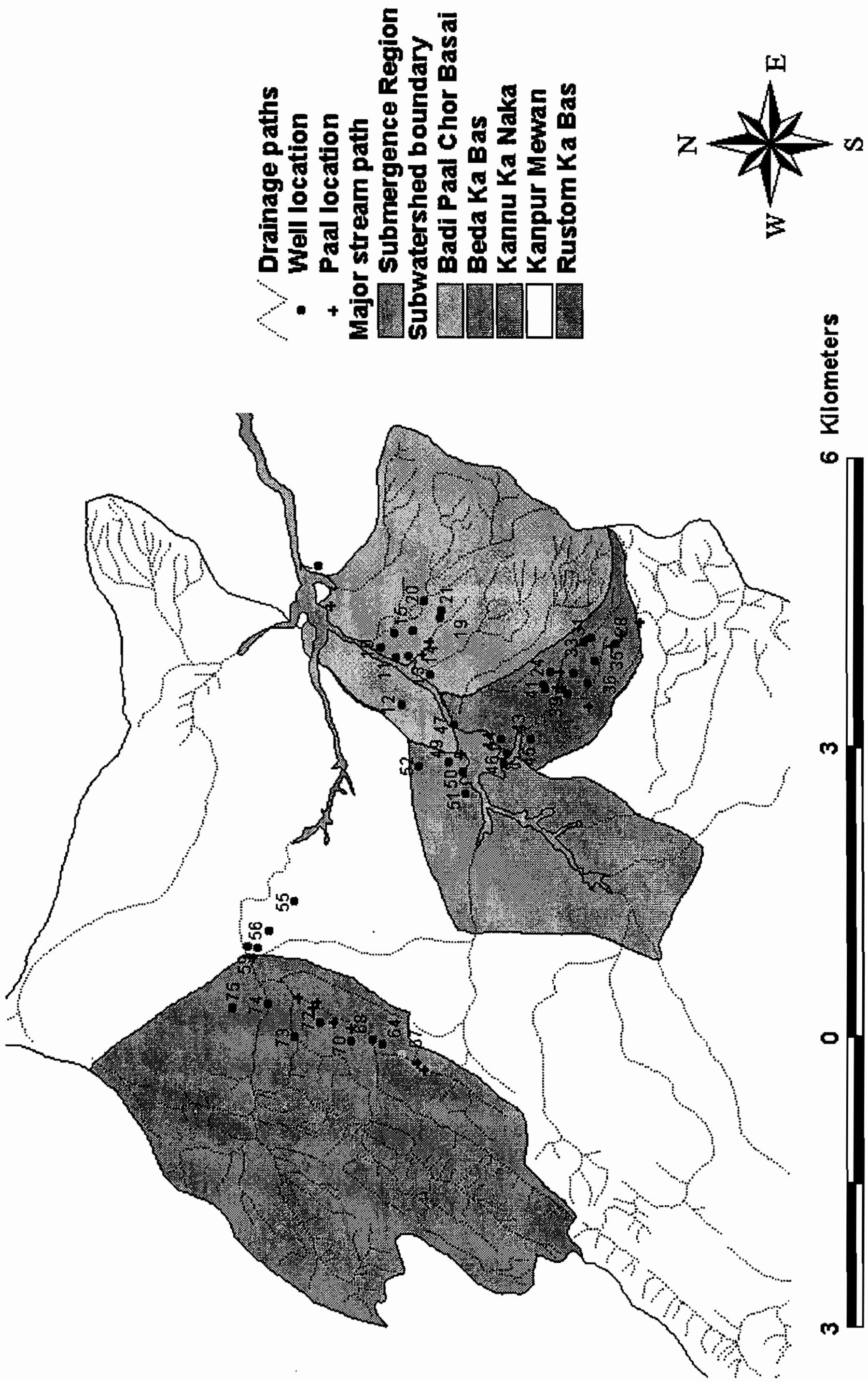


Figure 1. Hydrographic features of the study area.

The study area has a dry climate with hot summer, a cold winter and a short monsoon. Winter starts around mid-November and extends through February, while the summer follows thereafter and lasts till June. The southwest monsoon that brings the predominant rainfall in the region varies between July to mid-September for 30-40 days of active rainy days. The average annual precipitation (AAP) in Kishangarh Bas is 606 mm (Chawla, 2001), with highest rainfall recorded in 1917 (209% AAP) and lowest in 1918 (31% AAP). Annual rainfall recorded in the region during the last 25 years is presented in Figure 2. The mean annual rainfall for this period was 652 mm, and a coefficent of variation of 0.42. It is interesting to note that the high and low rainfall are bunching together, accentuating the draught and excess flow conditions. Within each year most of the rain either occurs between June-August or July-September. For the year August 2000 – July 2001, estimated annual reference evapotranspiration using Hargreaves and Samani (1985) was 1015 mm, and the rainfall during the same period was 425 mm. Data on cropping intensities, and land use that are being collected would enable further analysis of estimating the natural recharge and additional recharge due to Paals in the area through water accounting.

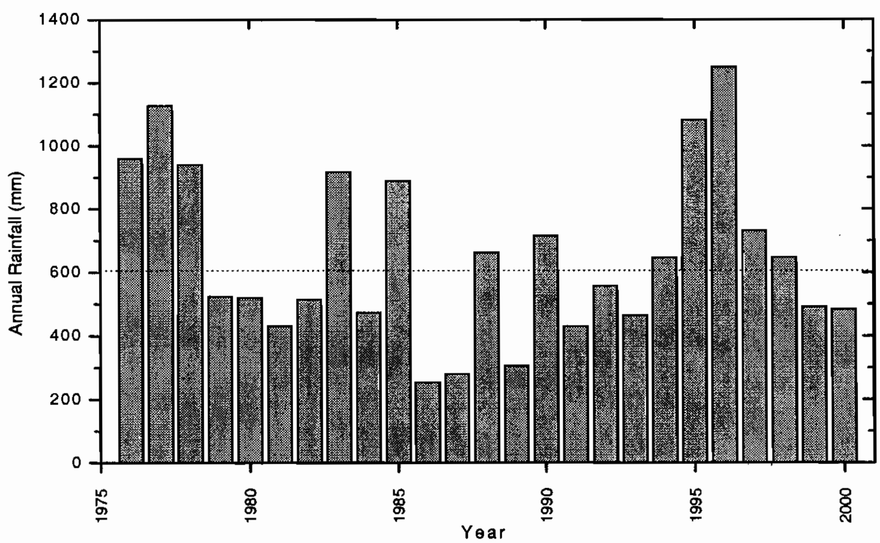


Figure 2. Annual rainfall at Kishangarh Bas during 1976-2000 (Chawla, 2001).

Most people depend on agriculture and animal husbandry for livelihood. A survey of randomly selected 88 farming families in the study region indicated that families of 6-10 are more common (Figure 3a). The practice of large families can be attributed to social and cultural practices typical of the region, which focuses on agriculture as a primary occupation. Average land holdings were less than 2 hectares a few decades ago, but this is gradually changing due to increased purchasing power amongst the farmers and urban migration of younger generation. From the farmers' interviews it was also noted that there were more farmers in the year 2000 who owned more than 2.5 hectares of land compared to a decade ago, the pre-intervention period. Present state of land holdings amongst the sampled farmers is presented in Figure 3b.

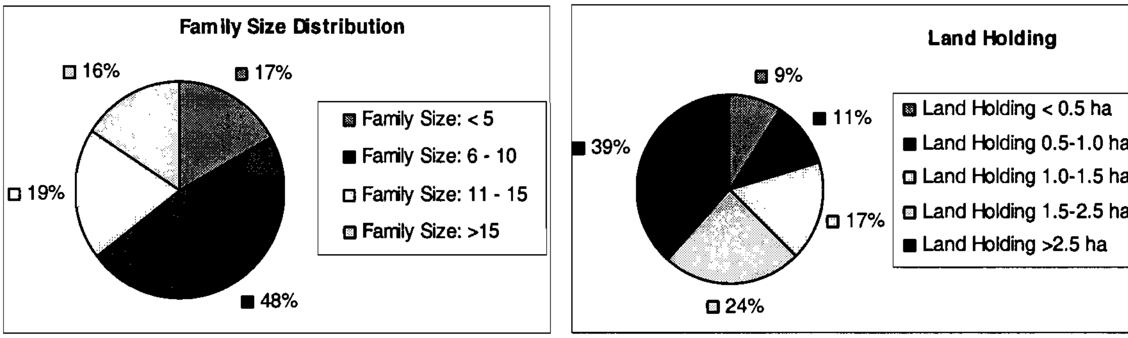


Figure 3. Distribution of family sizes (a) and land holdings (b).

Women in this area are mostly deprived and marginal, with less than 10% literacy. They are primarily responsible for their role in livelihood support system at household level including cattle rearing, fodder supply and domestic services. However their contribution to agriculture comes through labor intensive jobs such as weeding, hoeing, harvesting and sometimes watering. Until a few years ago, use of mechanical equipment, fertilizers, high-yielding varieties and pesticides was limited to large, progressive farmers. From the sampling studies conducted it was however observed that this is rapidly changing since the intervention (Figure 4). Farmers are now relying more on mechanized agriculture compared to the traditional use of draft animals for agricultural and hauling purposes. Although draft animals are still being used for agriculture they are more common amongst small and marginal farmers.

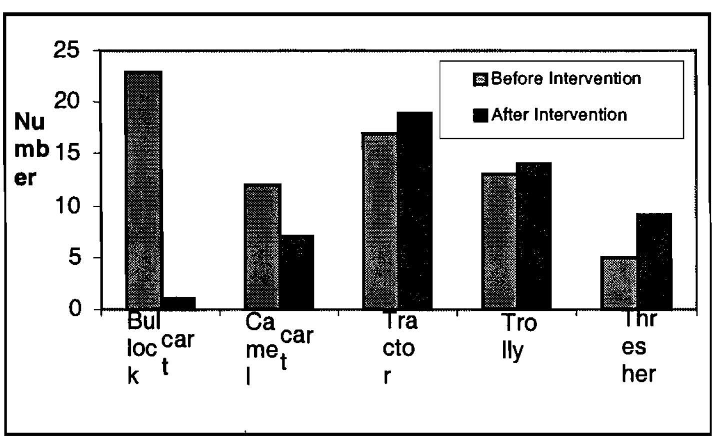


Figure 4. Trends in mechanization of agriculture before and after intervention

Large number of families rear cattle and goat primarily for self-employment and amongst poor and middle class families, as an additional source of income for livelihood. After the intervention it has been observed that livestock ownership has tremendously increased and is contributing to a major part of their gross income. Typical cropping practice in the study area involves a rotation pattern distinctly different for area accessible to water resources such as wells, submerged areas and the ones purely rainfed.

Table1. Crop seasons and cropping practice.

Crop season	*Period*	*Primary crops*	*Secondary Crops*
Kharif	mid-July – October	Millet, Sorghum, Gwar, Onion seed	Linseed, Cotton, Green fodder, Vegetables
Rabi	November – April	Mustard, Gram, Wheat, Onion seed	Barley, Green fodder, Rape seed
Zaid	May – mid-July	Onion	Chilly, Squash, Tomato

The crop rotation and intensity practiced differs also depending on the perceived well yield during the dry period and the topographic location of the land in the area. Generally, lands in the rainfed areas are usually on sloped lands adjoining the hilly regions, and are left fallow during Zaid season, so that farmers get more time to focus on their lands in irrigated plots. In the year 2000, cultivated area in all the four microwatersheds was more than 80 percent of the total land. A general summary of the physical features of the watershed is presented in Table 2. Quality of the soil varies from moderate productivity in the valleys to less productive in areas closer to the hilly region, where erosion is high. Much of the land surrounding the drainage paths and perennial flood areas are covered with alluvial deposits.

Table 2. Salient features of the micro watersheds

Sl.	*Particulars*	*Beda Ka Baas*	*Kannu Ka Naka*	*Rustam Ka Bas*	*Badi Paal Chor Basai*
1.	Total area (ha)	587	300	235	835
2.	Cultivated area (ha)	557	255	213	552
3.	Average landholding (ha)	1.5-2.0	1.00-1.25	1.5-2.0	1.50-3.00
4.	Soil types	Clavy-sand Sandy-loam	Sandy Sandy-loam	Sandy Sandy-loam	Sandy Sandy-loam
5.	Soil productivity	Medium-low	Low	Low	Low
6.	Number of families in micro watershed	66	120	75	114
7.	Families benefited	66	44	74	114
8.	Total number of Paals	14	10	20	31
9.	Paals repaired	10	2	15	16
10.	Total number of wells	18	70	39	80
11.	Number of wells before intervention	15	53	23	39
12.	Dry wells before intervention	15	6	4	6
13.	Average water level before intervention (m below GL)	20-22	18-20	22-24	16-19
14.	Average water level after intervention (m below GL)*	11-12	12-14	15-17	10-13

* Based on farmer's perception in an average rainfall water

Farmers in some microwatersheds are believed to be more progressive and entrepreneurial. The initial survey and interviews conducted in the study area indicated that this factor could not be associated with marginality of the farmers, whether or not they are medium or large, and to their ethnic background and even to the vicinity of their wells to paals. Progressive farmers were generally willing to take more risks in switching to different cropping and management practices, that some NGO's and GO's promote in the area.

Impact of Paal technology

From the summary presented in Table 2, it can also be noted that rise of the depth to water table was generally observed throughout the watersheds after revival of paals. A preliminary investigation from the topographic and hydrographic maps indicated that additional recharge in the study watersheds occurred mostly along the ephermeral rivulets in the submerged and surrounding areas around the paal structures (Figure 1). These areas also tap large quantities of subsurface water that flows down from the mountains towards the streams. From the hydrographic maps it was also found that the ephemeral rivulets in the plains have large areas that were prone to occasional flash floods. These flood areas could also be contributing to increased recharge in the plains affecting the well yield in the region. While areas that are far from the flood and paal areas received most of the water during monsoon directly through natural recharge, paals and adjoining areas received recharge through both direct, indirect and induced recharge due to greater pumping. A conceptual schematic diagram shown in Figure 5, explains the recharge phenomena combined with pumping in both naturally recharged areas and areas recharged with structures such as paals. The process of recharge is primarily different in both the scenarios due to continuous and prolonged residence time available for water to seep down in areas with paals resulting in increased amount of water recharged. Whereas areas subjected to natural recharge receive intermittent rainfall resulting in discrete time periods of recharge. In areas that have recharge structures such as paals, promote larger quantities of water to be added to the groundwater by continuous and pronlonged recharge.

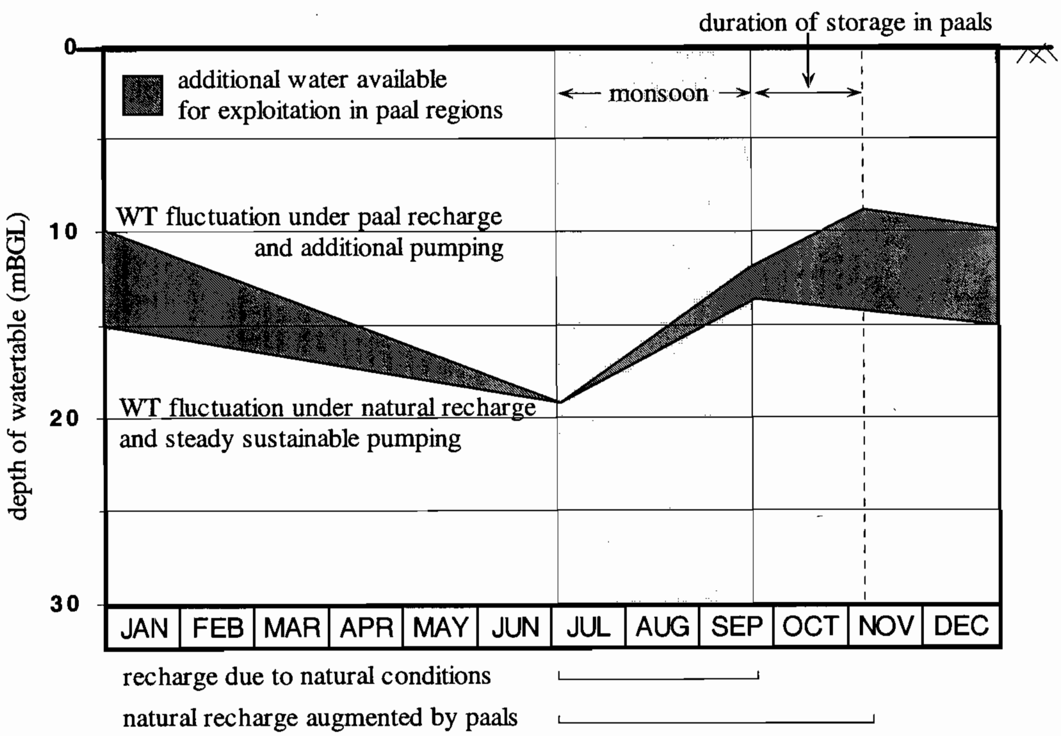


Figure 5. Schematic of water table fluctuations in naturally and artificially recharged areas.

In this study, 42 wells are being monitored which are spread in the study area both, in areas influenced by artificial recharge due to paals and natural recharge areas. Water table fluctuations are being recorded weekly to keep track of the effect of pumping and recharge. Results from observations made during August 2000-May 2001 are presented in Figures 6, 7 and 8. Figure 6 presents water table elevation above MSL as a function of distance from the line of recharge from paals and drains, for two periods - August 2000 and April 2001 representing post-monsoon and pre-monsoon peiods. Water table elevations of wells at a particular distance from recharge line varies over awide range between 20 to 25 metres. This is mainly attrributed to the fractures and fissures encountered by a particular well and brings out the fact that the hydrogeology of the aquifer is very inhomogeneous. As far as recharge pattern is concerned, there is no perceptible difference upto a distance of 500 to 600m from the line of recharge; moreover, the pattern is the same for both post-monsoon and pre-monsoon periods, indicating similarity in pumping pattern. A fact that emerges out of this figure is that as far as recharge to ground water is concerned, there is not much difference whether you are very near to the recharge line or far away (500 to 600m) from the recharge line and also the pumping pattern seems to be the same near the recharge line as well as away from the recharge line.

Figure 7 shows the trend in water table drop for the 42 observation wells for the period August 2000 to May 2001. There is only insignificant trend in water table drop as one moves away from the line of recharge, corroborating the observations made in Figure 6. The average water table drop is of the order of 3 meters, although it ranges from 0.75m to 5.5m at a particular section.

Figure 8 shows water table depth fluctuations as function of time at four typical locations for two wells (one within a distance of 200m from the line of recharge and another away from 200m of line of recharge). The figure also indicates number of hours of pumping for these two wells and rainfall occurrences.

Some of the important observations from Figure 8 are:

Water table depth of those wells near the line of recharge is less (14.8m)than those wells away from the line of recharge (17.3m). (Refer to Table 3).

Average lowering of water table depth from August 2000 to April 2001 is 3.52 m near the line of recharge while it is only 2.84m away from the line of recharge.

Pumping hours is more or less the same. 878 hours near the line of recharge while 840 hrs. away from the line of recharge.

Average area irrigated near the line of recharge is 2.89 ha as against 3.15 ha. away from the line of recharge.

The major advantage of being near the line of recharge is that the ground water is at a higher level than it is away from the line of recharge and consequently the pumping cost will be less near the line of recharge.

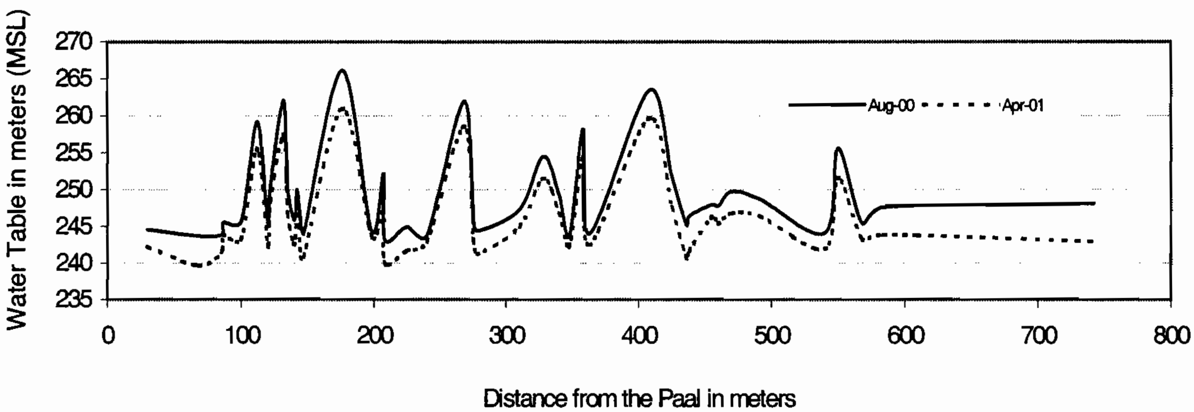


Figure 6: Water Table Variation for the 42 Observation wells for August 2000 and April 2001

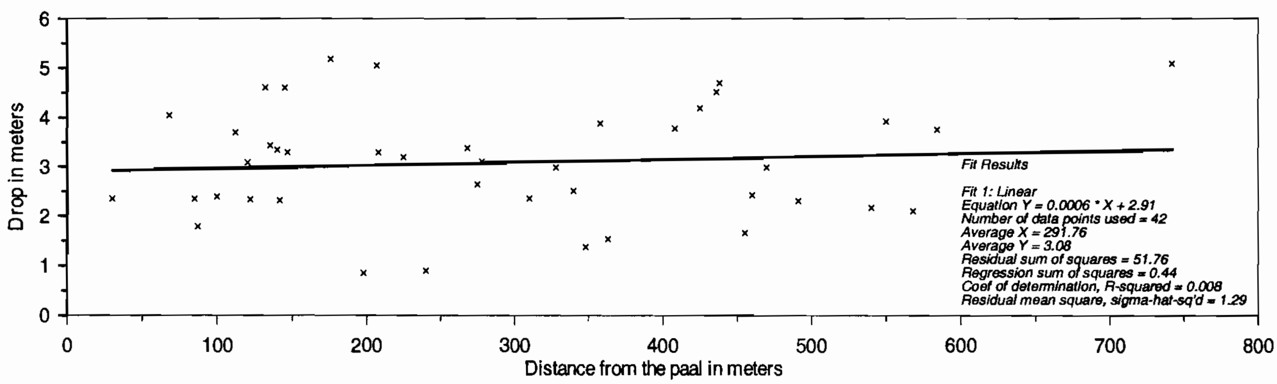


Figure 7: Trend in Water Table Drop (for the 42 observation wells)

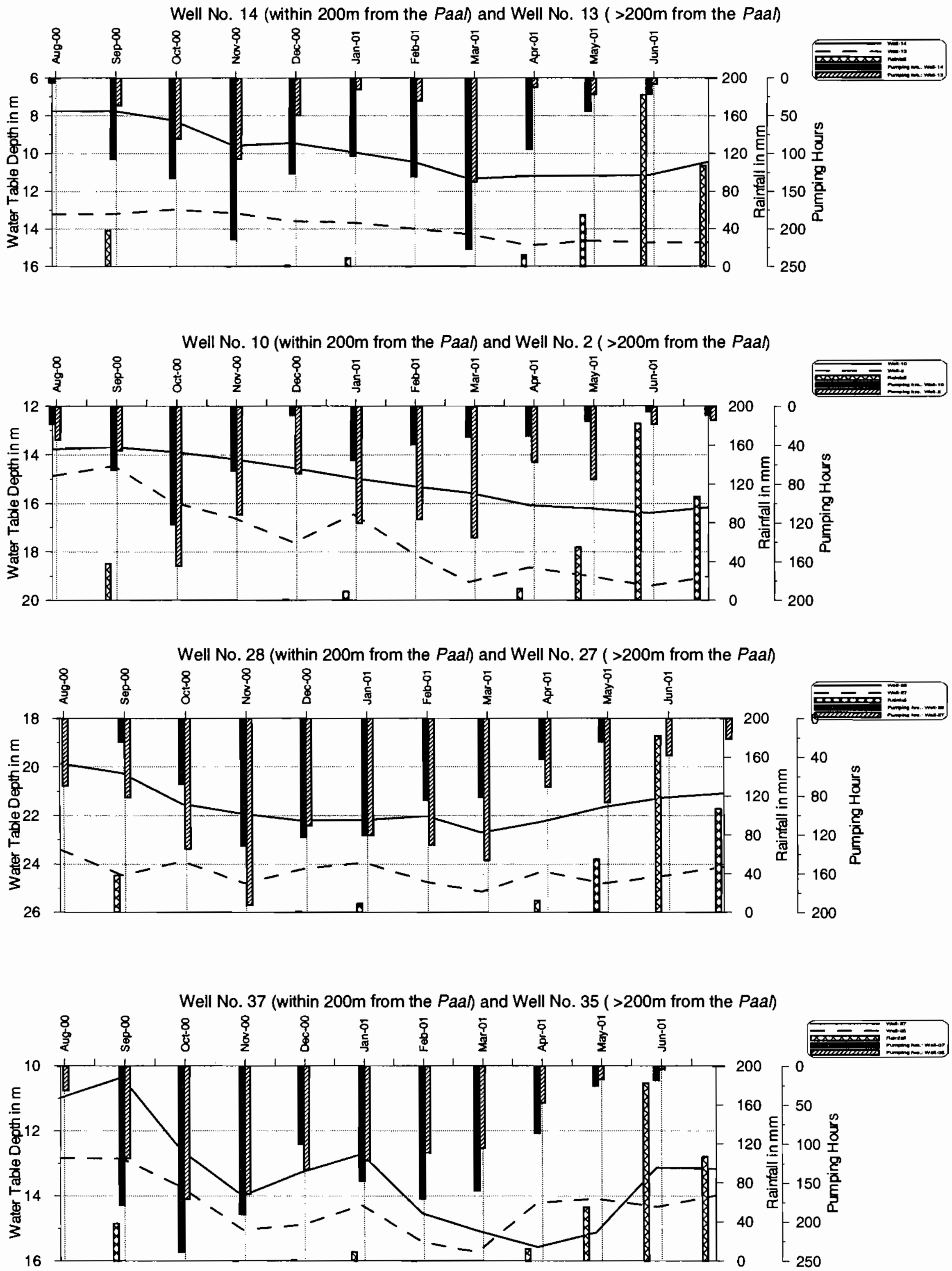


Figure 8: Water Table Depth from Ground Level for selected wells

Table 3: Water Table Depth Fluctuations

Description	*Wells Within 200m from Paals*	*Wells more than 200m from Paals*
Average Water Table Depth from Ground Level (m)	14.8	17.3
Average Lowering of Water Table: Aug 2000 to Apr 2001 (m)	3.52	2.84
No. of Pumping Hours	878	840
Average Area Irrigated (ha)	2.89	3.15
Recuperation Rate	Higher	Lower

In order to estimate the additional water recharged due to paal system, first an estimate of natural recharge was carried out. Then a ground water balance approach was used to estimate the additional recharge from paals. The work carried out by National Geophysical Research Institute, Hyderabad, India (Rangarajan and Athavale, 2000) using injected tritium studies indicates that for granite and gneissic aquifers, the replenishable ground water can be estimated by using the equation,

$$RE = 0.172 \cdot RF - 44$$

where RE = annual recharge (mm) and RF = annual rainfall (mm). Using this equation, the natural recharge for the year is estimated to be 26 mm (52 ha-m) or 6.5% of annual rainfall. For groundwater balance, the following were computed:

Total volume of water extracted using pumping units = 280-320 ha-m

Storage change in aquifer = 202-252 ha-m

Natural recharge = 52 ha-m or 6.5% of rainfall

Additional recharge from paal = 26-66 ha-m or 3-8% of rainfall[1]

Due to increased awareness of the role of paals in these microwatersheds it has also been observed that every year more new wells are being dug for groundwater exploitation. A comparative scenario presented in Figure 9 shows a general trend of drastic increase in the number of wells after intervention in all the microwatersheds studied. Every year more wells are being dug both in areas closer to paals and away. Wells dug farther away from paals have been augumented by insitu recharge practised by some farmers in their fields through raised field bunds. Hence, the rise in watertable in this area can be attributed to combined efforts of reviving paals and increased awareness amongst farmers for in-situ water harvesting: however impact of paals seems to be significant in inducing such a behavior.

[1] The variation in additional recharge from 3 to 8% of rainfall is due to assumption of specific yield of aquifer, which is uncertain.

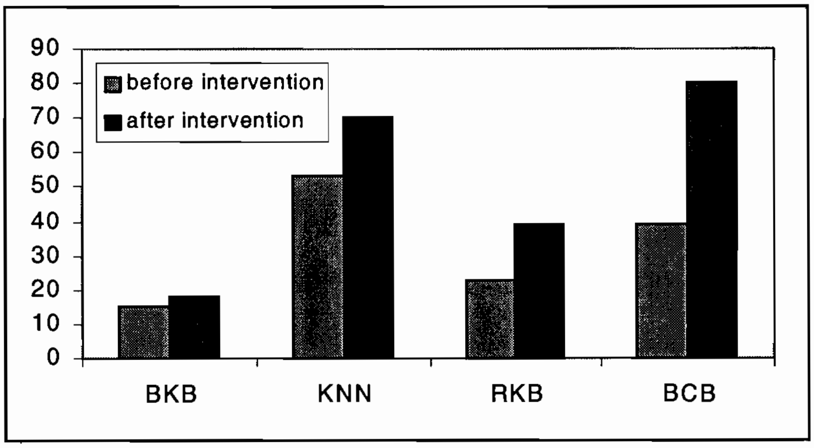
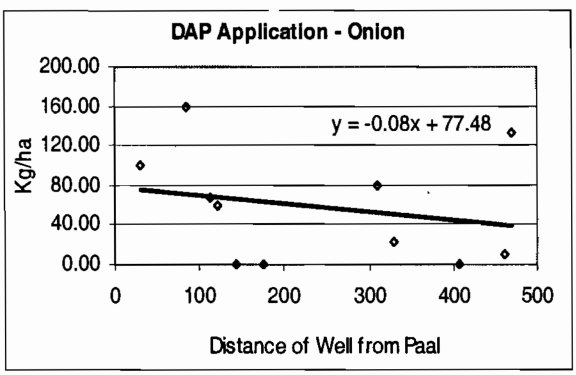
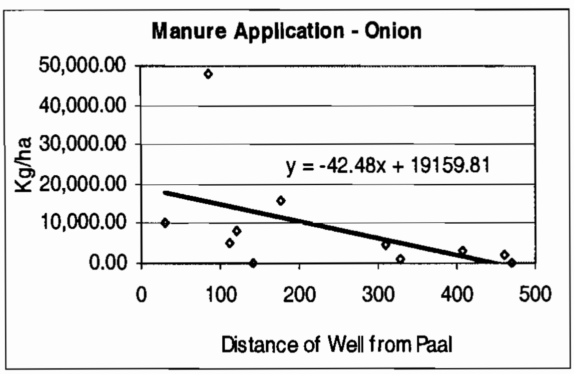


Figure 9. Comparative increase in number of wells in the four microwatersheds.

The survey noted earlier involved assessing socio-economic impacts in the microwatersheds due to paal implementation. The Alwar region is one of the largest producers of onion in the state of Rajasthan. A preliminary survey conducted showed that due to high returns in irrigated onion cultivation more farmers tend to grow onion than other cereal or vegetable crops. The survey also indicated that farmers who irrigated onion from wells closer to paals were also willing to invest more in better varieties and fertilizers due to assured water supply (Figure 8). It was also observed that these farmers preferred using more manure than urea. This could be due to convenience of disposing the manure to fields closer to the farm house or cattleshed, which also happens to be closer to wells. Farmers who had wells farther also applied most of their manure to plots closer to their farm house, but supplemented with more urea to make up for other inputs, including water. The yield data collected for the year 2000 showed that farmers who had their wells closer to paals were also able to produce more and make better profits than the well owners far from paals due to their perception of reliability of water supply (Figure 10).

The above quantitative impact assessment was made based on the data collected for the year 2000. A general survey based on a questionaire to assess farmers perception and understanding of the paal technology was made earlier during the project initiation resulted in obtaining their present purchasing capabilities and change in the value for fixed and mobile assets.





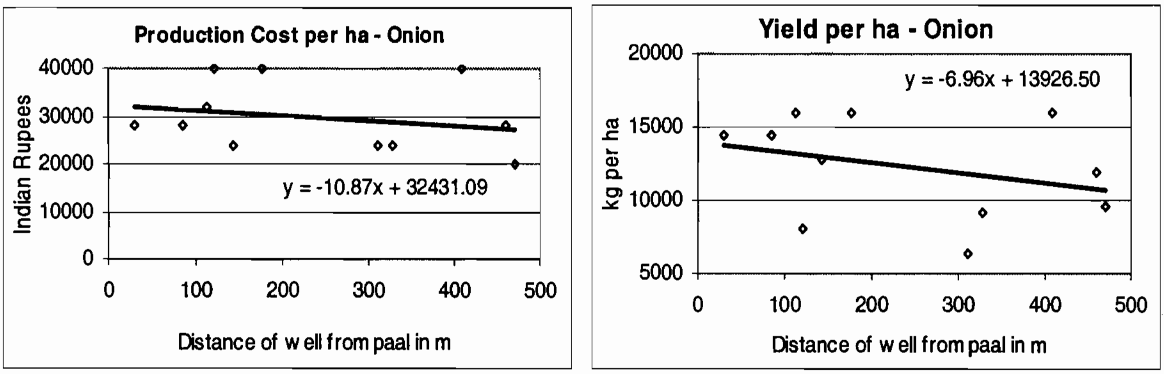


Figure 10. Production costs, inputs and yields for irrigated onion

Data collected for other crops such as millet and wheat indicated that most farmers chose to grow these crops mostly in rainfed conditions. Very few farmers took up these crops in irrigated areas mostly for domestic consumption and even these farmers did not use much irrigation during those seasons. However, to assess the impact of paals on water and crop productivity, only irrigated crops were seemed relevant and were accordingly analyzed. However, from the samples collected it was observed that prices of all fixed and mobile property in the area had increased tremendously since the revival of Paals (Figure 11).

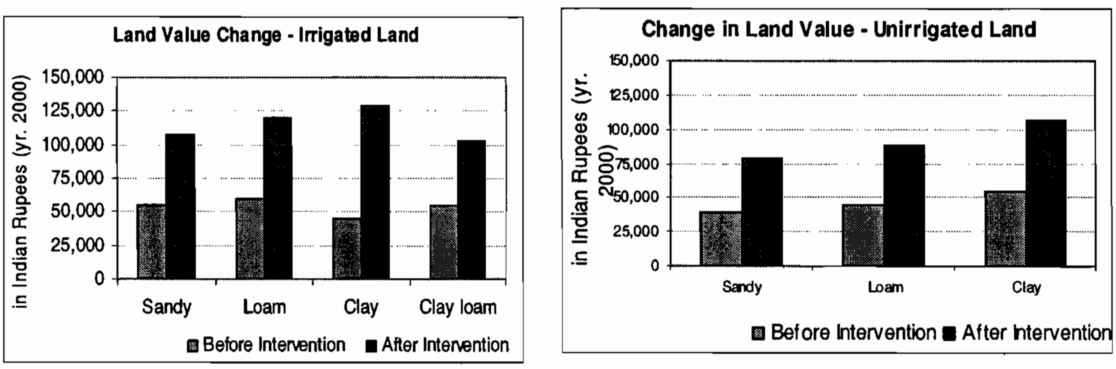


Figure 11. Rise in the value of irrigated and rainfed land

The value of land in the whole region seems to have increased tremendously due to increased buying power of an average farmer. Average increase in price of irrigated areas was 115% while the rainfed and non-agricultural land prices increased by 105%.

The results presented in this paper indicate prima facie evidence of the beneficial effects of paals in recharging the groundwater and their role in improving the livelihood of the farmers in the region. Further analysis is continuing, taking into account more recent hydrological and socio-economic process documentation data, with a view to highlight the purposes for which the recharged water is used and to assess the upstream and downstream effects of paals.

Summary

Paal systems are attractive low cost water harvesting and recharging structures well suited to semi-arid regions with hydrogeologic terrains similar to that encountered in North Eastern Rajasthan.

The natural recharge by rainfall during 2000-2001 is roughly 6.5 percent of annual rainfall. The additional recharge induced by paals is estimated to vary between 3 to 8% of annual rainfall, depending on the assumption made with regard to specific yield of encountered aquifer.

The additional recharge from paals helps to stabilize and decrease the depth of ground water pumping and allows to irrigate with high value crops.

Because of additional and reliable supply of ground water, mechanized and modern agricultural methods have taken roots in these traditional irrigation systems, property values have increased and off-farm income from ther sources such as livestock has also increased.

This is a continuing research; refined analysis of additional recharge due to paals including socio-economic analysis will be carried out with more data to be collected during the next two seasons.

Acknowledgements

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