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Upstream vs Downstream:
Groundwater Augmentation through Rainwater Harvesting and its Implications for Agricultural Development

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Sunil Ray*
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Introduction

The rationale that one seeks to justify revival of traditional practices of rainwater harvesting in a drought prone area, needless to mention, may override other development initiatives. The practices are simple, ecologically sensitive, people friendly and proven through century old tradition. However, colonial legacy that had a remarkable impact on designing development intervention pushed this tradition to the periphery (Shresth and Devidas, 2001). What underlies in this powerful tradition is that it is built based on the fundamental law of hydrology. It views hydrological cycle in its entirety in that no superficial distinction is made between ground and surface water (Chopra and Kadekodi, 2002). It recharges underground aquifers and makes groundwater reserve possible depending upon the nature of the former. Therefore, it is a 'dynamic resource' strictly from the viewpoint of a hydrologist (Chopra and Kadekodi, 2002). One may argue that approach to development and management of water, as followed after Independence, failed to appreciate this basic principle of hydrology. In its absence, forces of economic change in the drought prone area turned retrogressive as a sequel to repetitive ecological backlash. The synergy that existed earlier between ecology and economy broke down in that water was a significant component of the former.

While one acclaims traditional practices of rainwater harvesting as a step in the right direction, it is imperative to examine whether such a practice leads to result in uneven recharge of groundwater between upstream and downstream. In other words, does recharge of groundwater justify equitable allocation of groundwater between upstream and downstream when rainwater is harvested in the upstream of a river? or, is it the 'law of the water jungle' that says, 'he who is upstream is allowed anything; whosoever is downstream better get used to it.'(Kelman and Kelman, 2002).

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It is in this context that the present study is undertaken to examine what happens to the status of groundwater availability through recharge in the downstream vis-a vis upstream in the same river basin when rainwater is harvested simultaneously in both locations. Equally important is to examine its development implications especially for agriculture through intensification of irrigation in both locations. At the initiative of Tarun Bharat Sangh (TBS), an NGO, village communities of a large number of villages located in the upstream and downstream of the Arwari river basin in Thanagazi block of Alwar district brought back their traditional practices of rainwater harvesting. As many as 700 villages in 12 districts of Rajasthan were covered for conservation and management of water resources, which it was claimed, resulted in the regeneration of 6,500 sq. km of land and an increase in forest cover (Pangare, 2003). Bhaonta (upstream) and the other one, Samra (downstream) were two such villages of Alwar district where village communities constructed a large number of rainwater harvesting structures besides repairing the old ones during last one and half decades or so. The present exercise concentrates on these two upstream and downstream villages and examines how revival of traditional practices of rainwater harvesting affected groundwater recharge and brought about change in agriculture in respective villages.

The paper is divided into five parts. While the first part of the paper briefly describes physiography of the villages under study and drainage system of Arwari River, the second part is devoted to the estimation of groundwater recharge and its availability. The third part of the paper examines fluctuating trend of groundwater level of both upstream and downstream. The fourth part analyses its development implications for agriculture mainly in terms of intensification of groundwater-based irrigation and agricultural yield and the fifth part presents a few conclusions.

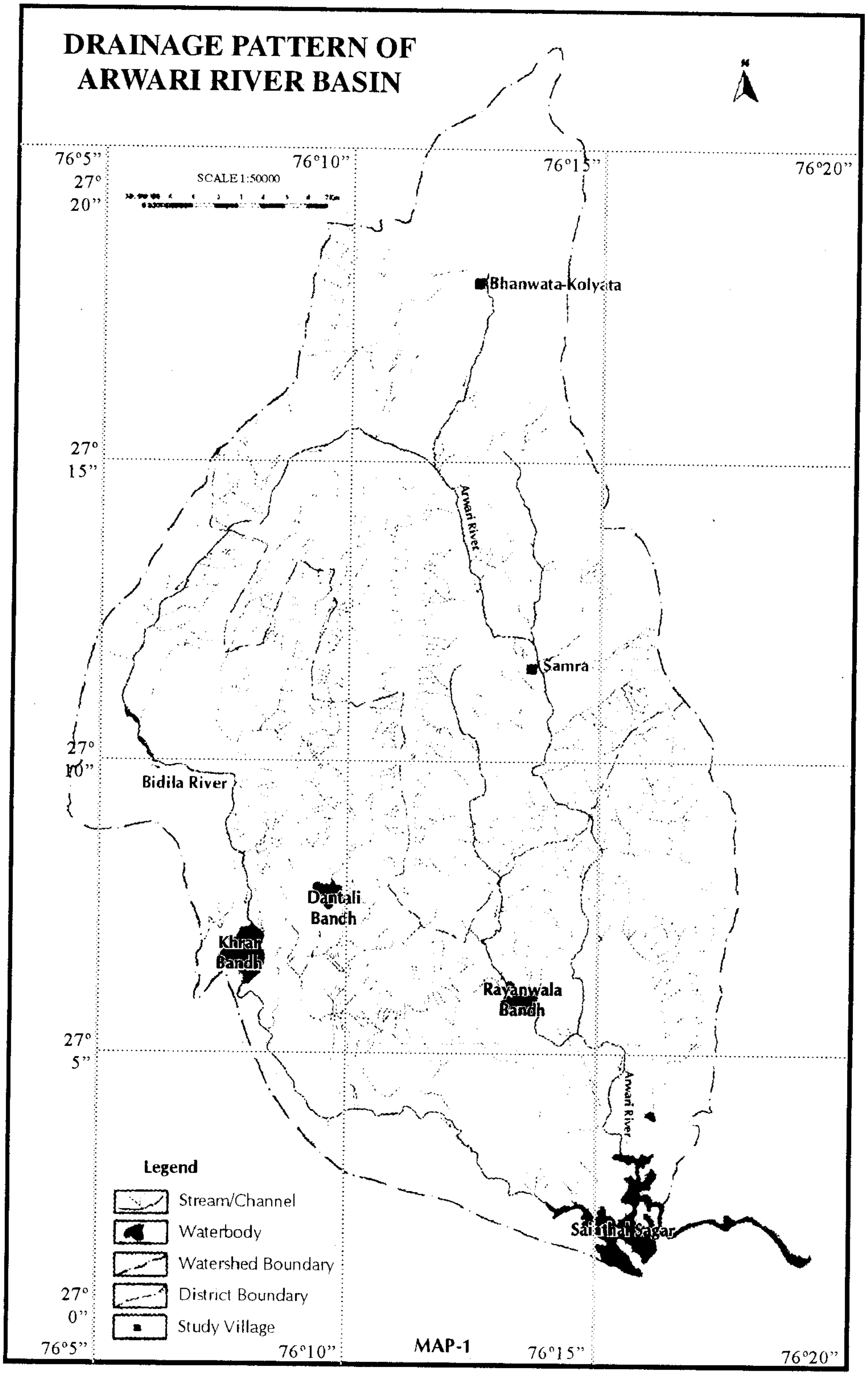
I

Physiography and Drainage System

One of the most influential factors that determine groundwater recharge is the hydro geological formation (rock structure), given the rainfall of the area. Villages of Thanagazi block including the ones under study are covered by Aravalli hills that run north to south and ranges in height from 300m to 600m. The region had more or less flat-topped hills between which lie fertile valleys. Apart from topographical differences, formation of the rock structures was dissimilar between the villages. While it was slate in Bhaonta, Samra had quartzite.

No significant difference is discernable between the specific yield of these rock structures. However, differences might occur in case fault in the rock develops. In such a situation, groundwater recharge increases while it never happens when no such fault occurs. The upstream village like Bhaonta has had the privilege of having small faults in its rock structure and its dips were more inclined towards the village. There was no fault in the rock structure of Samra (Govt. of Rajasthan, 1999). In other words, capacity to recharge groundwater was 'naturally' under favorable condition in the upstream as compared to downstream.

Soil in both upstream and downstream villages was primarily brown light loam that varied between reddish brown to dark reddish brown. Bhaonta, a tiny village with a total number of households of 55



Source : Survey of India, 54 A/4,7,8

was located nearer to one of the sources from where Arwari River originated. The downstream village was Samra with a total number of 291 households.

Besides repairing the old ones, different types of structures were constructed at different points of time since late 1980s in both villages. They included johads, bunds, anicuts, paal/ medbandi, talai, talab etc. Within an area of 3.39 sq.km, Bhaonta-Kolyala had 30 such structures, while Samra had 46 structures in an area of 20.57 sq.km. These structures were owned both by private and village community. One of the major sources of the river, as the drainage system shows, originates near Bhaonta and flows from north to south where it joins Santhalsagar (Map-1). The other source of the river originates near the village Agar. There are many tributaries of Arwari River joining in Samra. However, two of them are main tributaries – one which flows from Jhiri side (North of Samra) and the other one was that flows from Piplai Jagannathpura side on the east of Samra. The mainstream of the river stretches for 45 kms covering a catchment area of 503 sq.km. The river was not a perennial one. It flows only during the rainy season. All 70 villages, 35 villages each of Thanagazi and Jamwa Ramgarh blocks of Alwar district settled down in the catchment area of this river for last several centuries.

II

Estimation of Groundwater Recharge and its Availability

In order to estimate groundwater recharge in both villages under study, guidelines recommended by the Groundwater Estimation Committee appointed by the Ministry of Water Resources, Government of India, during 1997 were followed[1]. This was a revised version of the one recommended by the same during 1984. The revised version is illustrated briefly in the following model (also see Appendix).

Model

Several factors were taken into consideration for estimation of groundwater recharge in each year from 1988 to 2001. These included geographical area of the village, fluctuations in the groundwater level, crop yield, drafting of groundwater (agriculture+ domestic), and rainfall during monsoon and non-monsoon period etc[2]. Data on specific yield of ground water with the given underground rock structure of both villages were collected from Groundwater Department, Government of Rajasthan. It was 0.03 mcm (million cubic meter) per sq. km. of the area in both villages. Besides, new variables were also generated from the basic data as mentioned above and incorporated into the model.

One must bear in mind that recharge of groundwater of any year is assessed based on the data available on each factor pertaining to previous five years. This is done in order to normalize recharge of ground water of that concerned year as per the Groundwater Estimation Committee. Hence, groundwater recharge in both villages after 1988-89 might be treated more as an outcome of the efforts made for harvesting rainwater given the same rainfall. The method for estimating total annual ground water recharge for any assessment year is as follows:

$$TGWR = TRM + TRNM \qquad \text{———(i)}$$

{TGWR=Total normal ground water recharge, TRM=Total recharge during monsoon season, TRNM = Total recharge in non-monsoon season}

While,

$$TRM = ANMR + TRS \qquad \text{———(ii)}$$

{ANMR= Accepted value of normal monsoon rainfall recharge, TRS=Total recharge from other sources}

Accepted value of normal monsoon rainfall recharge is obtained by rainfall infiltration factor (R.I.F.), which is constant.

$$MRIF = PA * NMRA * R.\ I.\ Factor \qquad \text{———(iii)}$$

{MRIF = Monsoon recharge by R. I. Factor, PA = Potential Area, NMRA = Normal monsoon rainfall of the assessment year, R I F = Rainfall infiltration factor}

Rainfall infiltration factor is 0.08, which is constant for Thanagazi block (Dixit et.al., 2001). The following linear regression equation is used in order to estimate normal recharge of groundwater during monsoon

$$\text{Normal recharge} = A * \text{Normal monsoon rainfall} + B \qquad \text{———(iv)}$$

(Where A and B are the coefficient in the regression analysis)

While estimating accepted value of normal monsoon rainfall recharge, R.I.F, as mentioned earlier, assumes an important role. As per the Estimation Committee, normally there is a deviation between normal recharge and recharge by R. I. Factor. However, if percentage deviation of recharge by R.I. Factor from normal recharge lies between ± 20, recharge by R.I.F factor may be accepted. And, if percentage deviation is less than –20, then 80 % of recharge by R. I. Factor is acceptable. However, if it is more than +20, then 120 per cent of recharge by R. I. Factor may be taken into consideration.

Similarly, for groundwater recharge during non-monsoon period,

$$TRNM\ (\text{Pre monsoon + Post monsoon}) = NRRNM + RFOS\ (Rgw + Rt + Rsw)$$

{NRRNM =Normal recharge from rainfall during non-monsoon season, RFOS=Recharge from other, Rgw =Monsoon recharge from ground water irrigation, *Rt* = Monsoon recharge from tank and pond, *Rsw*=Monsoon recharge from surface water irrigation}

As per the Estimation Committee, if normal non-monsoon rainfall is equal to or more than 10 per cent of normal annual rainfall of the assessment year, then

$$TRNM = R.\ I.\ F. * PA * NNMR. \qquad \text{———(v)}$$

(NNMR = Normal non monsoon rainfall)

If normal non-monsoon rainfall is less than 10 per cent of normal annual rainfall of the assessment year, it may be assumed that there is no recharge during non-monsoon season.

$$NGWA = TGWR - NDNM \qquad \text{———(vi)}$$

$$SGWD = NAV - TD. \qquad \text{———(vii)}$$

(NGWA =Net ground water availability, NDNM = Natural discharge during non-monsoon season, SGWD = Stage of Ground Water Development, NAV = Net availability, TD = Total draft for all uses.)

Based on the methodology, as explained above, total annual ground water recharge per square km. including monsoon and non-monsoon is estimated in respect of both up- stream and down stream villages under study and shown in Table 1. Interventions made by TBS in these villages took place during 1987-88. Hence, the status of annual ground water recharge roughly before 1990 and after, can fairly explain the differences made in the improvement in ground water recharge. The estimated results are shown in respect of each year from 1988 to 2001 for both villages in Table 1.

Table 1 : Annual Groundwater Recharge including Monsoon, Non-monsoon in Upstream and Downstream (1988-2001)

	Upstream (Bhaonta)			Downstream (Samra)		
Year	Recharge in Monsoon per sq.km. (Mcm)	Recharge in Non-monsoon per sq.km. (Mcm)	Total Recharge per sq.km. (Mcm)	Recharge in Monsoon per sq.km. (Mcm)	Recharge in Non-monsoon per sq.km. (Mcm)	Total Recharge per sq.km. (Mcm)
1988	0.0691	0.0042	0.0733	0.0685	0.0023	0.0708
1989	0.0691	0.0042	0.0733	0.0685	0.0023	0.0708
1990	0.0685	0.0153	0.0838	0.0457	0.0146	0.0604
1991	0.0691	0.0042	0.0733	0.0457	0.0018	0.0475
1992	0.0691	0.0155	0.0846	0.0457	0.0131	0.0589
1993	0.0703	0.0077	0.0780	0.0460	0.0026	0.0486
1994	0.0702	0.0165	0.0868	0.0454	0.0098	0.0552
1995	0.0697	0.0130	0.0828	0.0461	0.0097	0.0558
1996	0.0697	0.0127	0.0825	0.0461	0.0093	0.0554
1997	0.0702	0.0324	0.1025	0.0511	0.0278	0.0789
1998	0.0706	0.0164	0.0870	0.0571	0.0104	0.0676
1999	0.0714	0.0111	0.0826	0.0572	0.0029	0.0600
2000	0.0711	0.0101	0.0812	0.0686	0.0027	0.0713
2001	0.0707	0.0287	0.0994	0.0686	0.0222	0.0908

Source : Estimates based on the data collected respectively from Groundwater and Irrigation Departments, Government of Rajasthan.

Table 1 shows that groundwater recharge during monsoon, non-monsoon and total annual recharge was almost same for both villages before 1990. The total annual recharge of groundwater was 0.0733 mcm (million cubic metre) per sq. km in Bhaonta during 1988 and 1989, while it was 0.0708 mcm in Samra. However, after 1989 volume of groundwater recharge differed widely between both the villages in that it declined in Samra much below the level of that of Bhaonta. One can make out its trend clearly from Figures 1.a, 1.b and 1.c that depict the same estimated results of monsoon, non-monsoon and annual groundwater recharge respectively.

Ground Water Recharge Per Square Km in Two Villages during monsoon

monsoon

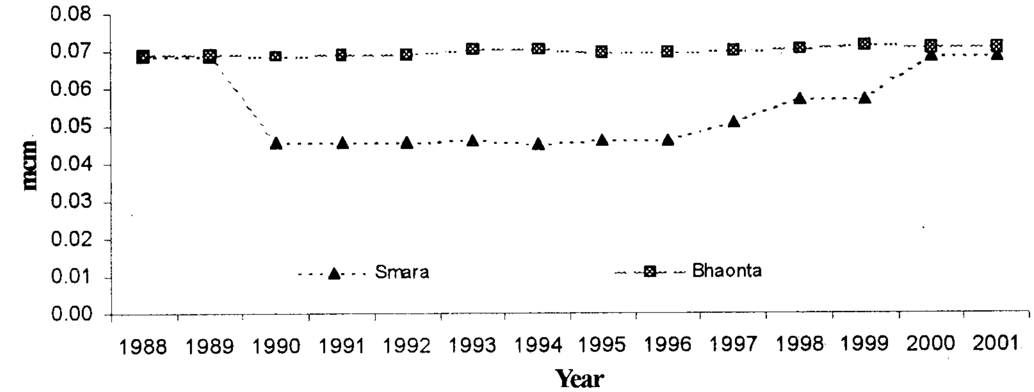


Figure 1.a

Annual Ground Water Recharge Per Square Km in Two Villages

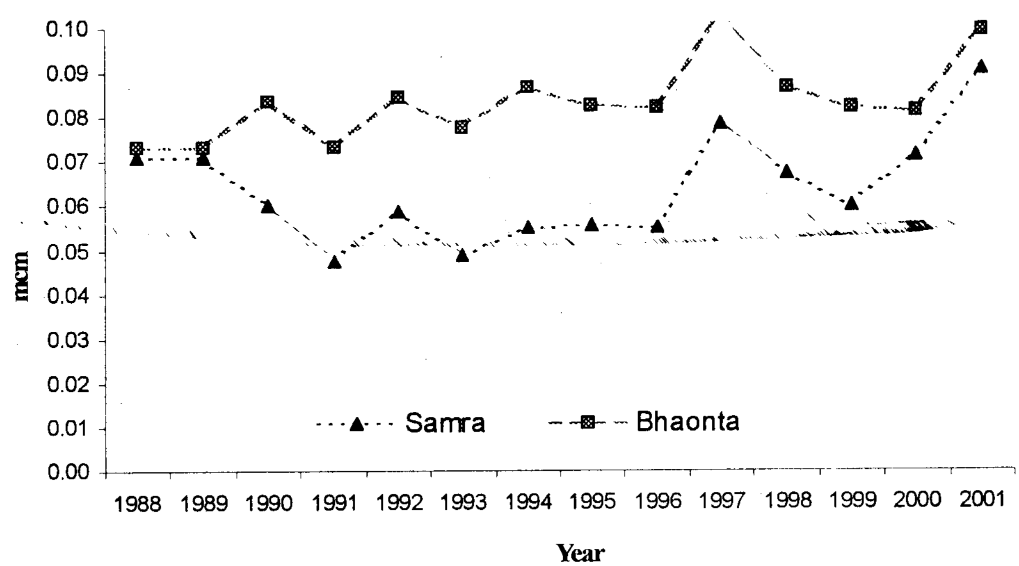


Figure 1.b

Annual Ground Water Recharge Per Square Km in Two Villages

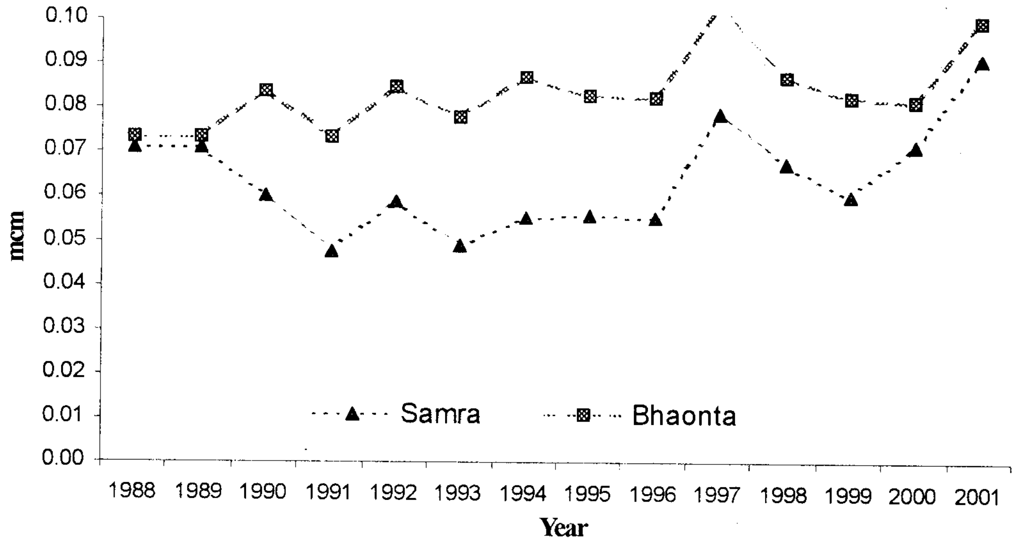


Figure 1.c

Figure 1.c shows that the gap in the volume of groundwater recharge per sq. km. started increasing between upstream and downstream after 1989 when water-harvesting structure made an impact. It widened further in the following years as revival of rainwater harvesting intensified in the upstream. It may be noted that new impounding structures were also constructed in downstream after 1988. Despite this, scale of recharge of groundwater in this was much lower than that of upstream village. Interestingly, gap between them narrowed down during 2000 and 2001. One may see it in Figure 1.c. This seemed to have happened firstly because these villages received more than average rainfall during the previous years that were taken into consideration while estimating groundwater recharge in these years. Secondly, there was no question of arresting run-off water during the drought years of 1999 and 2000 in the upstream that could have raised its ground water recharge more as compared to downstream. The all-pervading drought conditions did not allow such a gap to aggravate further especially after 2000. This seems to indicate that the status of recharge of groundwater remained unaffected in both upstream and downstream when both were affected by drought equally. Almost a similar condition existed before 1990, which was why, as Figure 1.c shows, recharge of groundwater during this period was almost same in both locations.

Downstream was likely to encounter three scenarios after 2001. The first one was the decline of recharge of groundwater in case drought continued to pervade these villages after 2001. In such a situation, question of run-off rainwater flowing towards the downstream from the upstream would never arise. The condition of recharge in the upstream would be same as downstream. The second one, however, would be different from the first one if rainfall was normal (not exceeding average rainfall) and no adequate quantity of run-off rainwater was allowed to flow towards downstream. In such a situation, recharge of groundwater in the upstream might go up while it might go down in the downstream leading to result in widening the gap between the two further. The third scenario was the one that might be an outcome of excessive rainfall (more than average) in the area. This was a favorable condition for increasing the scale of recharge of groundwater in the downstream. For, it was only under such condition that run-off rainwater could flow from upstream to downstream.

Hence, it is not only a question of how many water-harvesting structures are constructed in the downstream. Their importance can hardly be overstated, and, therefore, they do fulfill necessary conditions for recharging groundwater. However, the sufficient condition for groundwater recharge in the context of the same river basin with the same physiography is how much runoff rainwater is allowed to flow from the upstream to the downstream. Figure 1.a shows that groundwater recharge in monsoon per sq. km. was same in respect of both upstream and downstream villages before 1990. However, after 1990 recharge of groundwater per sq. km. during monsoon in upstream was much higher than that of downstream. It was around 0.07 mcm in Bhaonta, while 0.04 to 0.05 mcm in Samra although both villages received same rainfall. The status continued to remain almost same in both locations until 1999.

It was only after 1999 that the downstream could witness a rise in groundwater along with the upstream due to excessive rainfall, as mentioned above, in the previous years. Bhaonta, however, did not exhibit any noticeable change in the status of groundwater recharge during monsoon (although its level was higher than that of Samra). Normal rainfall of Thanagazi block is 705.4 mm. However, as Table 2 shows, the actual rainfall received during 1993 was 845.0 mm, 797.0 mm in 1994, 1016.0 mm in 1995, and 1194.0 mm in 1996, 810.0 mm in 1997 and 711.0 mm in1998. The rise of recharge of groundwater in the downstream village may be explained more in terms of cumulative effect of excessive rainfall (more than average) during these years.

Table 2 : Pre-monsoon, Monsoon and Post-monsoon Rainfall (mm) of Thanagazi Block, 1984 –2001

Year	Pre Monsoon	Monsoon	Post-Monsoon
1984	0.0	703.0	0.0
1985	0.0	650.0	76.0
1986	37.0	178.0	11.0
1987	143.0	331.0	17.0
1988	46.0	510.0	5.0
1989	6.0	418.0	0.0
1990	124.0	587.6	37.0
1991	5.0	279.0	38.0
1992	115.2	621.8	26.0
1993	73.0	845.0	0.0
1994	112.0	797.0	0.0
1995	86.0	1016.0	0.0
1996	75.0	1194.0	7.0
1997	27.0	810.0	286.0
1998	63.0	711.0	33.0
1999	49.0	629.0	0.0
2000	66.0	499.0	0.0
2001	220.0	334.0	24.0

Note : Normal Rainfall for Thanagazi Block is 705.4 mm.

Source : Irrigation Department (Hydrology), Rajasthan.

Downstream village like that of Samra had reasons to benefit from excessive rainfall. For, excess run off water is naturally let off towards the downstream once the maximum capacity of the existing structures to harvest rainwater was filled up in the upstream. This explains why groundwater recharge in Bhaonta was almost same throughout 1990 and early 2000. This also explains why groundwater recharge in Samra rose steeply in late 1990s. One may note that average rainfall before 1993 was lower than normal rainfall (Table 2). It means that there was no excessive run off rainwater to flow down during this period and, therefore, no positive impact was made on groundwater recharge in Samra. However, it did not make any serious difference to Bhaonta. For, it could harvest rainwater to whatever extent it could do so, depending upon the number and type of structures no matter what the rainfall was.

Figure 1.b shows no significant difference in groundwater recharge during non-monsoon period between upstream and downstream villages. However, even at a lower level, recharge in downstream village was consistently below upstream. The volume of recharge in both villages that was comparatively higher during 1997 and 2001, may be explained by the fact that non-monsoon rainfall received during same years was much higher than 10 per cent of the normal rainfall (as explained in the model).

In order to gain more insights into the changing status of availability of groundwater, it may be equally important to examine water level and its fluctuations during the same period corresponding to recharge of groundwater. For, water level and its fluctuations have a significant bearing on agro-ecological change.

III

Groundwater Level and its Fluctuations

One reads groundwater level based on at what depth from the surface it is available. It provides an appropriate condition for recharge of underground aquifers. In other words, deeper the level of groundwater, higher is the capacity of the aquifers to recharge through higher degree of infiltration of rainwater if there exists favorable hydrological conditions. The higher recharge of groundwater, in turn, contributes to the enhancement of groundwater level. Apart from water being recharged, other hydrological factors contribute to the enhancement of the level of groundwater. In order to examine fluctuations of water level in both upstream and downstream and its status before and after water harvesting structures were constructed, data on water level were collected from hydrographic stations located in respective places. For upstream village, data were collected from hydrographic station located at Agar ki Dhani, which was half a km. away from Bhaonta, and for downstream, the same were collected from the hydrographic station, which was located inside the village under study. Data were collected on water level during pre and post monsoon season in respect of both villages.

The seasonal (pre and post monsoon) fluctuations of groundwater level for almost last two decades are shown in Figure 2.a and 2.b. It appears from these Figures that groundwater level of Samra, the downstream village, during both pre and post monsoon session, was higher than that of Bhaonta, the upstream village, until 1988-89 when water-harvesting structures were constructed and began to

Groundwater Level (Pre-Monsoon)

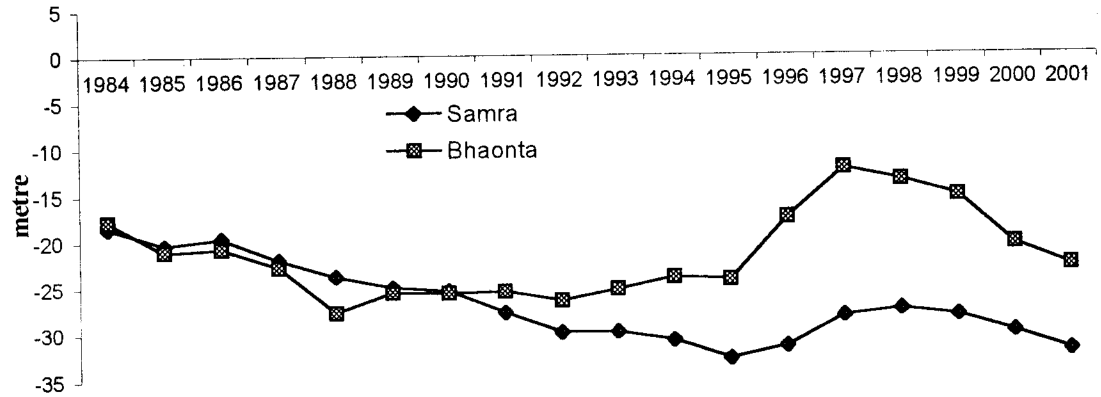


Figure 2.a

Groundwater Level (Post-Monsoon)

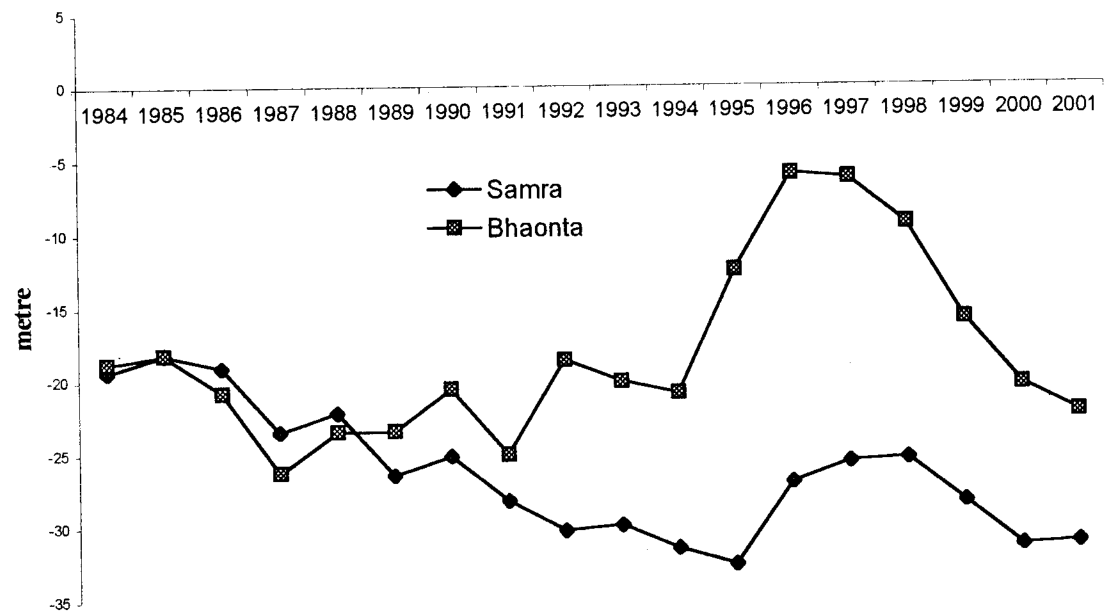


Figure 2.b

Source : State Groundwater Department, Govt. of Rajasthan.

prevent run off rainwater from flowing towards downstream. However, after 1990 groundwater level of the same was much lower than that of Bhaonta and continuously declined until 1994. As seen earlier, this part of the state received more than average rainfall consecutively for five years from 1994 to 1998. This might be the reason why groundwater level exhibited a rise in both villages, although level at which it increased in the downstream was lower than that of the upstream. Perpetual drought may be the reason for the decline of groundwater level in the following years.

In other words, had the flow of water in the Arwari river basin remained same (in the absence of human intervention for harvesting rainwater in the upstream), groundwater level of the downstream village would have been "naturally" above that of the upstream village. However, reversal of the trend of the level of groundwater of both villages, as Figure 2.a and 2.b show, seemed to have pushed the downstream village into having inferior status of the level of groundwater consequent upon the arrest of run-off water in the upstream. The statistical results as shown in Table 4 indicate that flactuation of groundwater before intervention was not significant while it turned out to be significant at 1 per cent level of confidence after rainwater harvesting structures were constructed.

Table 4 : Results of the Significance Test of Fluctuation of Groundwater Before and After Intervention

	Confidence Interval#		Significance (2-tailed)
	Lower	Upper	
Before Intervention	-3.57	0.97	0.211
After Intervention	-6.47	-1.37	0.007*

Note : #95% Confidence Interval, * Significant at 1%

Such a fluctuating trend indicated a better situation related to the availability of groundwater in the upstream. For, increasing availability of groundwater due to recharge definitely contributed immensely to agriculture in terms of expansion of area under irrigation and agricultural production. This is shown latter. However, the rise in agricultural activity, it seemed, did not comply with the quantum of recharge of groundwater under the given hydrological conditions. This might lead one to doubt whether such a positive change is sustainable.

As per the Groundwater Estimate Committee, if the rate of utilization of groundwater as a percentage of the available groundwater is above 70 per cent, regeneration (recharge) of groundwater becomes unsustainable. In view of this, one may see reversal of the present trend of availability of groundwater in the upstream in future. In such a situation, one is not certain how agricultural development will be adversely affected in Bhaonta. Figure 3 shows that the gap between annual recharge and draft was quite comfortable until 1993 in that annual draft was much lower than recharge in Bhaonta. However, subsequently after 1993, gap between the two narrowed down implying thereby draft of groundwater increased steadily. So much so, draft exceeded recharge of groundwater after 1998.

It may be noted that draft of groundwater in the upstream village went beyond 70 per cent of the recharge in almost all years after 1993. In other words, upstream village became vulnerable to shortage of groundwater after this year and reached a critical stage of its augmentation during 1998 when draft was more than recharge. The results of trend analysis show that groundwater was drafted annually at the rate of 0.011 mcm against annual recharge of 0.0027 mcm in the upstream during 1988-2001 (Table 5).

Table 5 : Results of the Trend Analysis of Annual Recharge and Draft of Groundwater in both Upstream and Downstream Villages

Upstream	Downstream
Annual recharge = 0.0027* (Year) + 0.1495	Annual recharge = 0.0217*(Year) + 1.0428
Annual draft = 0.0108 *(Year) + 0.0527	Annual draft = 0.013*(Year) + 0.3649

Source : Same as for Table 1.

Net Annual Recharge and Draft of Groundwater in upstream village

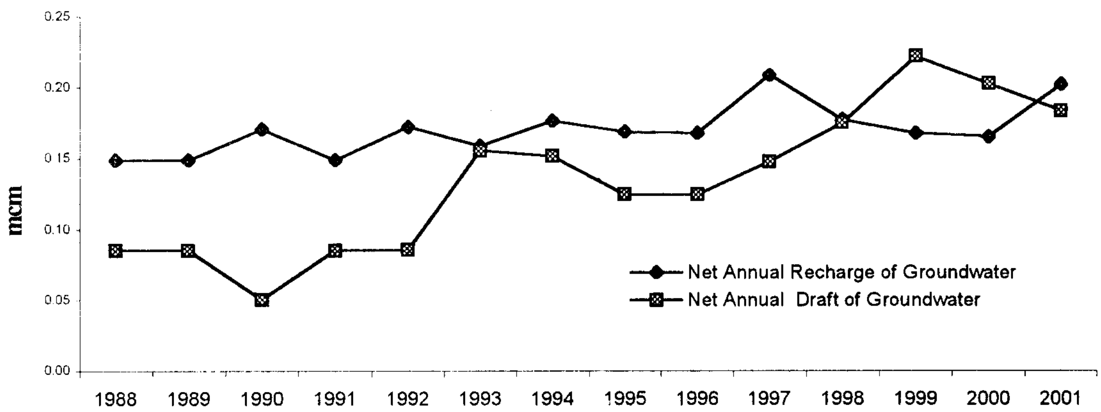


Figure 3

Source : Same as for Table 1.

Samra however, presents a different scenario altogether. Here, consumption of groundwater never exceeded 70 per cent of its availability. It was mainly because groundwater level went down by 30 metres after 1991 (Fig.2.a and 2.b). However, it was available in Bhaonta at a depth of 25 metres during the same year and much less than 25 metres in the subsequent years. This might be the reason why almost 90 per cent of the sample respondents of Bhaonta observed that there had been rise in the groundwater level while only 15 per cent in Samra. However, one must note that, as the field survey revealed, villagers of Bhaonta-Kolyala could gain access to that level of groundwater by means of deepening more than 50 per cent of the existing wells in this village. For, water level in this village, as shown in Figure 2.a and 2.b, continuously declined after 1996. So long as deepening of wells remains cost effective, farmers will continue to make their efforts to reach this level of groundwater. If more cropped area is brought under irrigation than what it is at present, it is quite likely that the farmers of the upstream village may be pushed into the situation where farmers of the downstream village are living at present.

In the case of Samra, the downstream village, drafting of groundwater was less cost effective due to water level being much lower accompanied by lower recharge. It was so low that it hardly, as Figure 4 shows, exceeded 0.50 mcm. This seemed to be the reason why annual recharge of groundwater remained above its annual draft. Figure 4 shows that volume of recharge remained almost constant within the range between 1.0 mcm to 1.5 mcm throughout the period under study.

Net Annual Recharge and Draft of Groundwater in Downstream Village

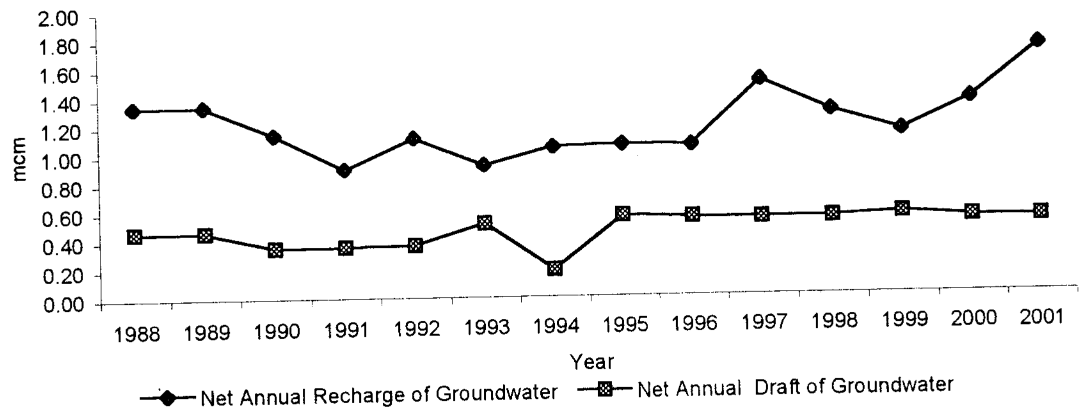


Figure 4

Source : Same as for Table 1.

The inequitable status of the availability of groundwater in two villages is also discernable based on availability of rainwater harvesting structure. Table 6 shows that one structure was available in each 11.3 hectares in Bhaonta-Kolyala, while the same was available at around 45 hectares of land in Samra. It also shows that density of wells was much less in Samra as compared to that of Bhaonta-Kolyala. While one well was constructed in each 10 hectares of land in Bhaonta-Kolyala, the same was done in each 18 hectares of land in Samra. Bhaonta-Kolyala had 35 wells spread over 339 hectares of land, while Samra had 116 wells in 2057 hectares of land.

Table 6 : Availability of Rainwater Harvesting Structure and Wells in Upstream and Downstream Villages

	Bhaonta-Kolyala[3]	Samra
Hectares of land per structure	11.3	44.72
Hectares of land per well	9.69	17.73

Source : Field survey.

IV

Changing Agricultural Scenario

The inequitable status of availability of groundwater after water-harvesting structures were constructed appeared to have led to the emergence of disparity in agricultural prospects between upstream and downstream villages under study. If we examine it from the point of view of bringing more land under irrigation, Bhaonta, the upstream village, may be considered as the one that benefited by it immensely. This is analysed based on the data collected from secondary sources and through field survey.

Irrigated area as a percentage of total cropped area in Bhaonta and Samra

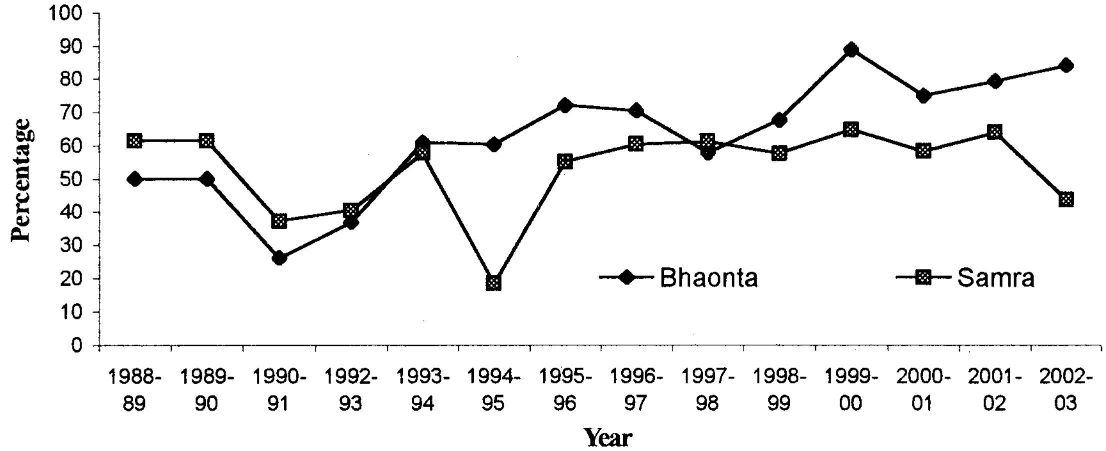


Figure 5

Source : Calculated on the basis of data available from Tehsil Office, Revenue Department, Government of Rajasthan

Figure 5 shows that the share of irrigated area of total cropped area of Samra, the downstream village, was little more than 60 per cent before 1990-91, roughly the year before intervention was scaled up. However, in the subsequent years, area under irrigation of the downstream village declined and continuously remained lower as compared to that of Bhaonta, upstream village, until 2002-03. Figure 5 shows that more than 75 to 80 per cent of the total cropped area was under irrigation in Bhaonta during three years of drought from 2000 to 2003, while it was around 40-50 per cent in Samra during the same period. Such a large percentage of area was brought under irrigation in Bhaonta even when water level witnessed a declining trend during these years as shown earlier in Figures 2.a and 2.b. The analysis at the household level in this regard substantially supports these observations. Table 7 shows that each sample household in Bhanota-Koliyala increased irrigated land by around 44 per cent during 2002-03, one of the drought years, as compared to what it was during the initial years of intervention (roughly around 1988-90). However, it steeply declined by 27 per cent in Samra during the same period.

Table 7 : Irrigated Land Per Sample Households in Both Upstream and Downstream Villages during Rabi Season

(land in bigha)

	Bhaonta-Kolyala	Samra
Initial year of intervention (1989-90)	2.52	6.00
During field survey (2002-03)	3.62	4.37
Increase (%)	43.65	-27.17

Source : Field survey.

In order to examine it further, data were collected from secondary sources randomly from a sample of 14 other villages from upstream and downstream of Arwari River respectively. The selected sample villages were the following: **Upstream** (Thanagazi block): (1) Bhaonta (2) Bhuriyawas (3) Jagannathpura (4) Chausala (5) Jhiri (6) Dumoli (7) Khardata (8) Sanwatsar (9) Chandpura. **Downstream** (Jamwa Ramgarh block): (1) Nimla (2) Hingawala (3) Kaljpuri (4) Shri Ramgopalpura (5) Ramyawala.

These villages were located closer to Arwari River and around 5 km away from it. The analysis of growth of irrigated area based on these data shows that percentage of irrigated area to the cropped area was higher in downstream villages than that of upstream ones before the practice of rainwater harvesting was revived in late 1980s (Figure 6). It was 50 per cent of the total cropped area in the case of the former, while less than 50 per cent in the case of the latter. However, in the following years, as Figure 6 shows, area under irrigation in all downstream villages declined and that of the upstream expanded. It had fallen below 50 per cent of the cropped area in the downstream and continued to be so until 1997-98. However, it increased in the following years with being less steep than the upstream villages that witnessed a rise in the irrigated area more than 70 per cent of the cropped area during the same years. It was possible to increase irrigated area to such an extent even in drought conditions due to, as mentioned earlier, rise of groundwater recharge, which in turn, was a result of excessive rainfall in the previous years. The decline of the irrigated area during 2002-03 in both upstream and downstream villages can be said to be an outcome of decline in groundwater level associated with low recharge. It was quite likely in the event of perpetual drought. Under such conditions, rise of irrigated area in upstream village like Bhaonta, as shown earlier, might prove unsustainable. In any case, area under irrigation differed significantly between upstream and downstream villages even during drought years. The sample villages in the upstream had 46 per cent of the cropped area under irrigation, while it was 35 per cent of the same in the downstream villages during 2002-03 (Figure 6).

The trend analysis of the growth of area under irrigation also shows that the latter had grown annually by 0.65 per cent in the case of the downstream village, while it increased by 1.99 per cent in the upstream villages. This was three times more than that of the downstream village.

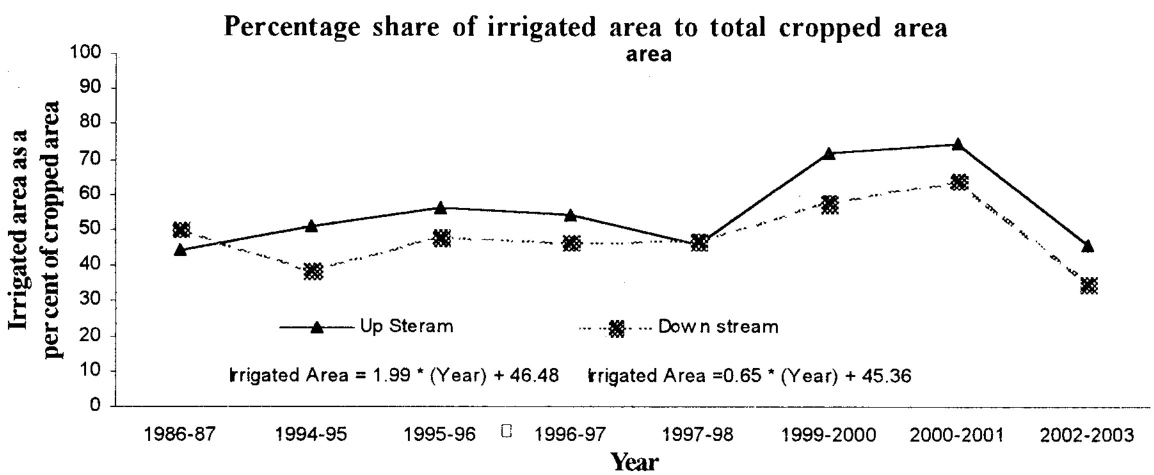


Figure 6

Cropping Pattern and Crop Yield

The preceding analysis shows that Samra, the downstream village, witnessed steady decline of area under irrigation. Such a decline seemed to have largely contributed to the low generation of income from agriculture as compared to that of Bhaonta. The analysis of cropping pattern and crop yield of both upstream and downstream villages present extremely different status of agricultural development between them. In order to examine whether area under each crop changed over the years after rainwater harvesting began in both locations, data were collected for 1988-89, the initial years of intervention and 2002-03, the year when rainfall received was very low. The results of the analysis are shown in Table 8.

The significant observation that one makes from Table 8 is that area under almost all crops except maize declined in the downstream village during 2002-03. Maize is a rain fed crop that saw expansion of its area over the years. However, the noticeable feature of the cropping pattern was that area under all Rabi crops including wheat, barley and mustard declined in the downstream village in this poor rainfall year while upstream village could gain by expanding the area under cultivation of these crops. In other words, area under Rabi crops in the downstream village declined by 45.61 per cent, while the same increased by 40.90 per cent in the upstream village. It may be noted that area under cultivation of some of these crops that showed declining trend during 2002-03 in the downstream, increased during the year when normal rainfall was received (not shown in Table 8).

Table 8 : Area under Different Crops in Upstream and Downstream Villages

(In Hectares)

Crops	Bhaonta		Samra	
Kharif	1988-89	2002-03	1988-89	2002-03
Maize	18	22	83	110
Bajra	8	11	36	27
Gwar	0	0	6	0
Jawar	9	1	1	0
Til	2	0	10	0
Jawarchari	0	0	4	0
Kalijiri	0	0	7	3
Vegetables	0	2	0	0
Rabi				
Wheat	6	13	38	28
Barley	6	9	33	27
Gram	4	0	6	0
Mustard	6	9	32	7
Methi	0	0	2	0
Dhaniya	0	0	5	0

Source : Tehsil Office, Thanagazi (Alwar district).

However, this is not the issue. The issue is whether agriculture could perform well even during the poor rainfall year due to construction of rainwater harvesting structures. It was in this context that one finds, as it appears from Table 8, downstream village failed to perform better in agriculture in terms of expansion of the area under cultivation especially under Rabi crops. Upstream village could afford to expand the area under Rabi crops even under perpetual drought conditions by way of, as observed in the preceding section, exploiting groundwater over and above the volume of its recharge. However, this was not possible for the downstream village to achieve. For, water level was beyond the reach of an average farmer.

The scenario of agricultural yield was equally disappointing for the downstream village. Yield of five major crops as reported by the sample households located both in upstream and downstream villages were taken into consideration for analysis. Crops included bajra and maize, which were grown in kharif season and wheat, barley, and mustard that were grown during Rabi season. Response of the households on yield pertained to 1988-89 and 2002-03. In the absence of the data from secondary sources on yield rate of these crops in these villages, interviews were held with the members of the sample households. Questions were asked about respective crop yield per bigha during the initial years of intervention and 2002-03 (a year earlier to when field survey was conducted)

Yield rate in terms of crop output per bigha of the sample households is estimated and shown in Table 9. Results are plotted in Figure 7. Figure 7 shows that yield rate of all Rabi crops witnessed a decline in the downstream village, while the same increased in the upstream village. It is important to note that the decline of yield rate was maximum in respect of mustard crop in downstream. It was –4.68 per cent. However, upstream village witnessed a maximum rise of the same crop by 16.45 per cent. Of all crops, mustard turned out to be major source of gains in agriculture in terms of increased yield in Bhaonta after rainwater harvesting began. Table 9 shows that, although the yield rate of rain fed crops such as bajra and maize increased by 1.13 per cent and 2.49 per cent respectively in Samra, the rise was much more in respect of the same crop in the upstream village. It was 13.82 per cent and 4.65 per cent for bajra and maize respectively.

Percentage Increase of Yield per Bigha in Both Upstream and Downstream Village

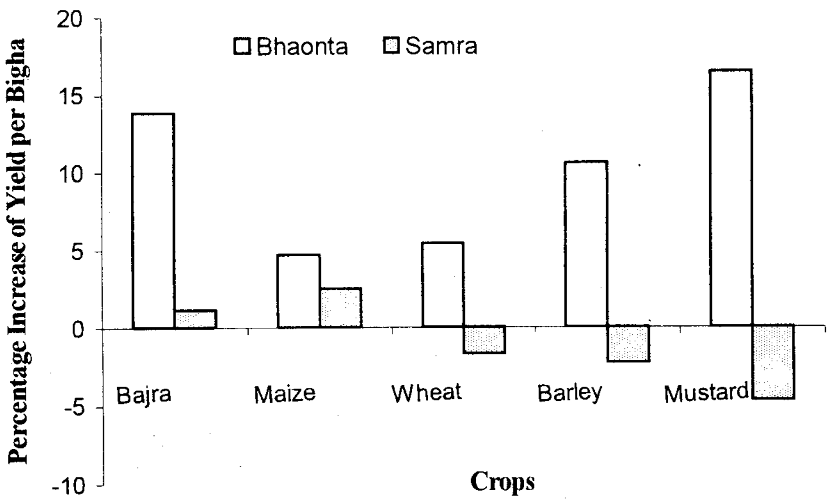


Figure- 7

Source : Field survey

While other factors such as use of fertilizer had a role to play in enhancing crop yield, availability of water for irrigation was the primary consideration that one could hardly ignore. Field survey revealed that the sample households of the downstream village used less than half of the quantity of fertilizer that was used in the upstream village during 2002-03. It was estimated to be 9.05 kg (DAP+Urea together) per bigha on an average taking all crops together in the upstream village, while it was 4.01 kg in the case of the downstream village. In other words, agricultural scenario even in respect of improvement in crop yield seemed to be more encouraging for upstream than downstream. The relative disparity in agricultural performance associated with intensification of irrigation and improvement in crop yield between upstream and downstream in the same river basin fairly indicates a sort of development dichotomy in agriculture in that one grew at the expense of the other.

Table 9 : Yield Rate of Main Agricultural Crops of Sample Households of Bhaonta-Kolyala and Samra (per bigha)

Crop	Bhaonta-Kolyala			Samra		
	Initial years of Intervention (1989-90)	During field survey (2002-03)	Percentage Increase	Initial years of intervention (1989-90)	At the time of field survey (2002-03)	Percentage Increase
Bajra	2.46	2.80	13.82	2.65	2.68	1.13
Maize	4.30	4.50	4.65	3.61	3.70	2.49
Wheat	7.20	7.59	5.42	5.39	5.30	-1.67
Barley	5.20	5.75	10.58	4.41	4.31	-2.27
Mustard	3.10	3.61	16.45	1.71	1.63	-4.68

Source : Field Survey

If development gains were to be assessed based on valuing agriculture crops and by- products in market prices, Samra, the downstream had no reason to see why its agriculture could prosper like that of upstream under the present situation.

IV

Conclusions

No alternative may be discernable to rainwater harvesting for ensuring rural livelihood in a state like Rajasthan that faces frequent drought. The revival of its traditional practices may improve agro-ecology interaction, which an interventionist seeks to achieve. However, operational moorings that shape the nature of intervention have much to do with the sustenance of such practices. One may, therefore, be curious to know, in the present context, whether an integrative and comprehensive land and water management of the complete catchment area was ever considered (Pangre, 2002). For, it is a single watercourse system in that natural resources such as soil, water and vegetation are interconnected. Impacts of intervention on one resource affect the status of others suggesting nonseperability of their externalities (White and Runge, 1994). Besides, it suggests co-ordination between landholders of both upstream and downstream. In the absence of the latter, land productivity of downstream farmers declines (White and Runge, 1994).

Without giving explicit recognition to the need for integrated management as explained above, revival strategy of rainwater harvesting is bound to be discrete and village centric, no matter whether the village is located upstream or downstream. The present study shows that the approach that was followed by the intervening agency towards land and water management was essentially village centric. Social cost that it entailed in terms of development gains being unequal between upstream and downstream might go unnoticed in the immediate terms. Even the upstream village like Bhaonta might fail to escape from such eventuality because of mismatch between production and consumption of groundwater despite achieving comparatively higher level of groundwater recharge. The present study shows that the village gradually entered into unsustainable zone in late 1990s, when draft of groundwater far exceeded its recharge.

It exemplifies a case of 'induced' expectation of the village community of the upstream for more agricultural gains without having its root to sustainability. The availability of groundwater at a manageable depth (in terms of costs incurred) in the upstream stood out to be the principal source of generation of such individual rational expectation. However, intensification of irrigation purely guided by private gains beyond a point and its consequence on increasing requirement of groundwater might push the village community back in the immediate future to a state of underdevelopment where they lived some years ago. The potential social hazards are invincible in such situation especially when Gram sabha, the local institution as initially developed by the villagers at the initiative of TBS, was practically found to be in operational and riddled with host of conflicts. One does not know whether such Gramshava can ever be revived when private initiative for rainwater harvesting gained overriding importance at the sponsorship of the intervening agency. Inequality may then have sufficient ground to breed even in the upstream, not to talk about it between upstream vs downstream alone.

Notes

1. Guidelines were collected from the Groundwater Department, Government of Rajasthan. It was followed by a series of discussion with the hydrologists and geo-hydrologists of this department and Central Groundwater Board, Jaipur.
2. In the absence of the data on rainfall in the respective villages under study, the same was collected for the block to which these villages belonged.
3. Kolyala was a hamlet adjust to Bhaonta. Although it belonged to another revenue village, same of its agricultural lands were located in the same place where lands of the villages of Bhaonta were located. This was the reason why geographical areas of both were taken together for instruments.

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Appendix

GUIDELINES FOLLOWED FOR ESTIMATION OF GROUNDWATER RECHARGE

COLUMN NO.	COLUMN TITLE	EXPLANATION
1	Year	
2	Potential Zone Area (Sq. Km)	
3	Water level fluctuation (m)	
4	Specific Yield (%)	
5	Gross Kharif Draft (Agriculture + Domestic) mcm	25% of gross agriculture draft of particular year plus domestic draft of 120 days of that year
6	Monsoon recharge from ground water irrigation Rgw (mcm)	25% of gross agriculture draft of particular year multiplied by factor depending on range of water level (25% for <10m, 15% for 10-25m and 5% for> 25 m water level)
7	Monsoon recharge from seepage from canal Rc (mcm)	
8	Monsoon recharge from surface water irrigation Rsw (mcm)	
9	Monsoon recharge from Tank & Ponds Rt (mcm)	
10	Rainfall Recharge Ri (mcm)	Col. No. 2x 3x 4 + 5 - 6 -7- 8-9
11	Gross Agriculture draft (mcm)	No. of wells x operational days x yield per day (Ltr)
12	Gross Domestic Draft (mcm)	No. of wells x 365 x yield per day (Ltr)
13	Normal monsoon Rainfall r (normal) (m)	Normal monsoon rainfall for the particular year
14	Monsoon Rainfall ri (m)	Actual monsoon rainfall for the particular year
15	(ri X ri) (Rainfall X Rainfall monsoon) (m)	Square of col. No. 14 (Required for the constant (a) (b) for regression analysis
16	(Ri X ri) (Monsoon Rainfall ri X Recharge Ri)	Multiplication of Col. 10 & 14
17	Block	
18	Type of Area	
19	Potential zone	
20	S1 (Sum of Rainfall in monsoon) (m)	Sum of Col. No. 14
21	S2 (Sum of Rainfall recharge in monsoon) (mcm)	Sum of Col. No. 10
22	S3 (Sum of Rainfall X Rainfall monsoon) (m)	Sum of Col. No. 15
23	S4 (Sum of monsoon Rainfall X Recharge)	Sum of Col. No. 16
24	(a) (Constant)	{(No. of Assessment years x Col. No. 23) – (Col. No. 20 x 21)} , {(No. of Assessment year x Col. No. 22) – Square of Col. No. 20
25	(b) (Constant)	{Col. No. 21 – (24 x 20)} x No. of Assessment year
26	R normal (Linear regression method) (a x r-normal + b)	Col. No. 24 x normal monsoon rainfall of the Assessment year + Col. No. 25
27	R. I. Factor (%)	

COLUMN NO.	COLUMN TITLE	EXPLANATION
28	Monsoon Recharge by R. I.F. Rrf (normal rifm) (mcm)	Col. No. 2 x Normal monsoon rainfall of the Assessment year x Col. No. 27
29	Variation (PD) (%)	% deviation {(Col. No. 26 - 28) , (Col. No. 28) } x 100
30	Accepted value of normal monsoon rainfall x (normal rifm) (mcm)	If % deviation is in between – 20 and + 20 than accept Col. No. 26, If PD is <-20 than accept 80% of Col. No. 28, If PD is > + 20 than accept 120% Col. No. 28
31	Total recharge from other sources (mcm)	Sum of Col. No. 6, 7, 8 & 9 of Assessment year
32	Total recharge during normal monsoon season R(normal) (mcm)	Sum of Col. No. 30 & 31
33	Block	
34	Type of Area	Command, Non-command & Saline
35	Water bearing formation	
36	Potential zone area (Sq. km)	
37	R. I. Factor (%)	
38	Normal non-monsoon rainfall (m)	Of the Assessment Year
39	Normal Annual Rainfall (m)	Of the Assessment Year
40	Normal Recharge from Rainfall during non-monsoon season (mcm)	If Col. No. 38 is equal or more than 10% of Col. No. 39 than Col. No. 36 x 37 x 38, otherwise no calculation required
41	Recharge from Ground water irrigation Rgw. (mcm)	75% of gross agriculture draft of particular year multiplied by factor depending on range of water level (25% for <10m, 15% for 10-25m and 5% for > 25m water level)
42	Non-monsoon recharge from seepage from canal Rc (mcm)	
43	Non-monsoon recharge from surface water irrigation Rsw. (mcm)	
44	Non-monsoon Recharge from Tank and ponds Rt (mcm)	
45	Recharge from other sources (Rgw + Rc + Rsw + Rt) (mcm)	Sum of Col. No. 41, 42, 43 & 44
46	Total Recharge in monsoon season (mcm)	Sum of Col. No. 40 & 45
47	Total normal Annual ground water recharge (mcm)	Sum of Col. No. 32 & 46
48	Natural discharge during non-monsoon season (mcm)	Allow natural discharge in monsoon season in terms of base flow and sub surface inflow/ out flow (5-10% depending on the area)
49	Block	
50	Area of block (Sq. km)	
51	Type of area	
52	Water bearing formation	
53	Potential zone area (Sq. km)	
54	Net ground water availability (mcm)	Minus Col. No. 48 from Col. No. 47

COLUMN NO.	COLUMN TITLE	EXPLANATION
55	Existing gross ground water draft for irrigation (mcm)	Of the Assessment year
56	Existing gross ground water draft for domestic and industrial use (mcm)	Of the Assessment year
57	Existing gross ground water draft for all uses (mcm)	70% of Col. No. 55 + Col. No. 26
58	Present ground water balance as on Assessment year (mcm)	Minus Col. No. 57 from Col. No. 54
59	Water requirement for domestic and industrial as on year 2025 (mcm)	Not required
60	Allocation for domestic and industrial requirment as projected for the year 2025 (mcm)	Col. No. 59 58
61	Stage of ground water development (%)	(Col. No. 57 , 54) x 100
62	Whether significant decline in pre monsoon water level (Yes/No)	Prepare hydrographs and assess
63	Whether significant decline in post monsoon water level (Yes/No)	Prepare hydrographs and assess
64	Category	If Col. No. 61 is <70 than categorise the zone as Safe, if between 70-90 categorise as Semi Critical, if between 90-100 categorise as Critical, and if>100 than categorise as Over Exploitation
65	Annual Potential Recharge (mcm)	Recharge of areas where water level is <5m. and consider 5m. for fluctuation and than multiply area of the shallow water zone by specific yield and fluctuation calculated in this column

Source : Dixit, M, et.al. (2001), *Reappraisal of Groundwater Resources of Alwar District*, Ground Water Department, Government of Rajasthan.