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Impact of rainwater harvesting on groundwater recharge in water stressed Aravali hill ecosystem

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ABSTRACT

Alarming ground water extraction to expand irrigation in *Aravali* hill ecosystem disregarding low rainfall, sandy soils and harsh climate created water crisis in this region. Under a corporate supported initiative, 194 earthen dams were constructed and 1250 ha of waste lands were leveled to harvest rainwater to recharge ground water between 2006 and 2013 in 40 villages of Alwar district of Rajasthan. In one typical village, 15 earthen dams were constructed and 85 ha of private waste lands were leveled. The reservoir areas were contour surveyed to find storage capacities. Daily rainfall and fortnightly observations from seven wells were recorded to find out changes in groundwater level. The records of all the tube wells were compiled by household survey to assess the level of ground water extraction. Between 1982 and 2012, the number of tube wells increased from 2 to 128 lowering mean water table by 3.6 m. 64 shallow tube wells had to be converted to submersible motors from 2007 to 2012.Though 15,03,800 cu m rainwater was harvested from 884.89 ha of rocky *Aravali* hills but this effort could not reverse the trend of ground water depletion. Data revealed that when there was no reservoir in nearby area of observation wells but number of submersible motors were installed on nearby reclaimed lands and cropping pattern changed in favour of vegetable crops; there was clear drop in water table making the scenario unsustainable for irrigated agriculture. Where there were number of reservoirs nearby, the drop was much less in spite of two to three submersible motors nearby indicating chances of sustainability. Out of seven observation wells, only one indicated the chances of sustainability, two showed partial and four no chances of sustainability. The land reclamation activity not only promoted installation of more bore wells on reclaimed land but also reduced water inflow to the reservoirs thus reducing the scope of rainwater recharge. Reducing area under summer vegetable crops, retaining sufficient area under traditional Pearlmillet and Mustard, expanding area under drip and sprinkler irrigation and regulation to control the number of new bore wells appeared the only way out of this complex problem.

1. INTRODUCTION

The ground water resources in India are depleting at a much faster rate than replenished triggering serious concerns for sustainability of irrigated agriculture (CGWB, 2005; Nagaraj *et al*., 2011). The situation is particularly serious in arid ecosystems where irrigation expanded disregarding low rainfall, sandy soils, harsh climate and almost no canal water recharge (Katiyar, 1999; Narain *et al.,* 2006). Tube-well irrigation became a major development effort and area under irrigation increased six folds in sixty years in Rajasthan putting large areas under dark zones and made draft levels unsustainable (Rathore, 2005; Bhan, 2009). The *Aravali* hills forming part of this arid ecosystem were no exception. The removal of vegetation cover by excessive fuel wood extraction and overgrazing resulted in severe land degradation, loss of precious rainwater as runoff with concomitant adverse environmental and socio-economic consequences impacting the quality of life (Singh *et al.,* 1990). What was once a predominantly pastoral economy was transformed into a tract of arable farming with huge overdraft of ground water by ever-increasing number of bore wells and the entire region faced water scarcity (Aggarwal and Narain, 1997; SPACE, 2011; Agnihotri and Grewal, 2013).

The rainwater harvesting for ground water recharge was suggested the only way to sustain the level of irrigation in this region (Singh and Sharma, 2003). Moreover, the rocky/stony terrain of this tract offers the possibility of harvesting run-off by suitable rainwater harvesting structures (Narain *et al*., 2006). Although watershed based development was attempted in Haryana *Aravalis* but the end result was a drop in ground water because the number of bore wells increased manifold after the project (Grewal *et al.,* 1992; Singh *et al.,* 1990). In Dujod watershed of Sikar district of Rajasthan, the construction of 96 runoff control structures over 3306 ha watershed resulted in increase in water table but irrigated area increased from 140 to 210 ha and this resulted in more groundwater extraction (MoA, GoI, 2001).

In a similar study conducted in Bajni watershed of Datia district of Madhya Pradesh, the watershed interventions led to increased ground water table but number of bore wells increased from 2 to 12, area irrigated from 8.2 to 48.0 ha and volume of water withdrawn from 1.97 to 11.50 ha-m and as a result, the real objective of ground water recharge due to water harvesting structures was not achieved (CSWCRTI, RC Datia, 2004). Nema *et al.* (2003) suggested that high level of extraction has to be reduced to make a balance between recharge and use. In terms of sustainability, the results of CGWB (2005) indicated that recharge interventions alone may not reverse the long term problems of ground water overdraft. The studies by DFID (2006) suggested that the evaluation of potential of aquifer recharge through watershed treatment is necessary in different agro-ecological and hydro-geological conditions. Taking the case of Rajasthan, Claire and Willem (2008) held that investments on rainwater harvesting for ground water recharge are increasing despite little knowledge of impacts of catchment hydrology.

A review of these studies indicated that long term micro level critical analysis of rainfall amount and distribution, reservoirs storage capacity created, rain water harvested and recharged, trend of water depletion as indicated by regular well observations and changes in cropping pattern was lacking. To what extent the intensive rainwater harvesting and land development measures under natural resource management initiatives can sustain the expanding irrigation by increasing number of bore wells in *Aravali* hill ecosystem was a question for which precise answer supported by long term data was lacking. With this background, the impact of rainwater harvesting for ground water recharge in a typical *Aravali* micro-watershed were studied for seven years and salient results are summarized in this paper.

2. MATERIALS AND METHODS

In the water starved *Aravali* hills, the study of hydro-geological conditions indicated that rainwater harvesting can be attempted by two main ways *i.e.* constructing of earthen dams across gullies emerging from barren rocky hills (*Ex-situ* rainwater harvesting) and leveling and bunding of privately owned uneven and gullied sandy type lands situated below the hills (*in-situ* rainwater harvesting). Making the above two interventions as main part of a corporate supported project taken up in 40 villages located in foot of *Aravali* hills of *Tijara* block of *Alwa*r district of Rajasthan, 194 earthen dams locally called *Paals* were constructed between 2006-13 to harvest runoff from the barren rocky hills. Simultaneously, 1250 ha of privately owned wastelands were leveled and bunded on which field crops and tree plantation was raised. In a typical study village, out of 15 *Paals*, 3 were on community/common land and 12 on private land. Two *Paals* on community land have large catchment area of 210 and 357 ha. Three *Paals* having 4 to 5 ha catchment area of private lands were gully plugs and land above them was leveled and put to crops. The detailed analysis of the entire scenario of rainfall, runoff harvested, ground water recharge and extraction was made in seven study villages out of which one typical village Gotoli was selected. This village is nestled in the foot of *Aravali* hills and falls in Tijara block of Alwar district of Rajasthan. Out of total 15 *Paals* constructed in village Gotoli, two representatives were selected for detailed monitoring. The results were extrapolated for the total *Paals* constructed in the village. The impact assessment study was carried out from 2006 to 2013. Daily rainfall was recorded by installing two ordinary rain gauges.

Contour survey of all the experimental reservoirs was done and depth *vs.* water spread area and depth *vs.* storage capacity were worked out and curves drawn. Gauges were installed in the reservoir area to record rise and fall in water levels on daily basis till there was water in the reservoirs. There was no other use of reservoir stored water except little bit for livestock drinking. The stored water tended to disappear quickly in the sandy strata. The main loss of water was through seepage and evaporation. The total loss in depth of water from the readings of graduated gauges was recorded on daily basis. The evaporation loss from study reservoirs was worked out on daily basis following the standard method prescribed by Meyer (1942) and Thornthwaite and Holzman (1942). The data of monthly pan evaporation from Standard U.S Weather Bureau Class A Evaporation Pan was obtained from the Regional Research Station Bawal of Haryana Agricultural University Hissar which represents the area. The loss of water through evaporation from larger water bodies is less than the loss from the standard pan, so daily pan evaporation rate of that month was multiplied by a factor of 0.7 and taken as actual evaporation from the water bodies as suggested by Frevert *et al*. (1955). From the daily water levels of the reservoir of two consecutive days, the spread area was determined from depth *vs.* spread area curve and averaged out. The average water spread area was multiplied by a factor worked out from monthly evaporation rate day^{-1} taken from pan data and further multiplied by 0.7 to get loss through evaporation from the water body. For example:

Say the water spread area on day -1 at 5.6 m depth of water given by gauge = 2.87 ha; The water spread area on day -2 at 5.0 m depth of water given by gauge = 2.00 ha; The total storage at 5.6 m height say was= 3.2 ha (taken from depth *vs*. storage curve); Total storage on second day at 5.0 m height say was = 2.5 ha-m; So loss through evaporation = Average spread area (ha) x daily pan evaporation rate x 0.7.

$$= \frac{2.87 + 2.00}{2} \text{ x 6 mm x 0.7}$$

$$= 2.43 \text{ x } \frac{6}{1000} \text{ x 0.7 = 0.0102 ham}$$

Total loss of water in one day = 3.2-2.5 = 0.7 ha-m; Loss of head in one day = 5.6-5.0 = 0.6 m; Seepage loss = Total loss of water- evaporation loss = 0.70-0.0102 = 0.69 ha m; Daily ground water recharge (assumed as 80% of seepage loss) = 0.69 x 0.8 = 0.55 ha-m; On daily basis, ground water recharge was calculated till water was stored in the reservoir and summed up.

The rate of percolation was very high in these sandy soils. Sometimes, when water level in the reservoirs was in the range of 4 to 5 m high, more than one meter of water percolated in one day and evaporation loss was less than one cm day^{-1}. As the reservoirs got filled up, the rise in water table was reflected in two to three days in the observation wells down below.

Seven open wells below the water harvesting dams were selected and used to record ground water levels at fortnightly interval. One piezometer was also installed in an area where no well was available nearby. All records of old and new bore wells installed were obtained from each and every farmer through household survey in a pre-designed proforma. The crops grown, irrigations given to each crop were recorded to get the volume of water used for irrigation in the command areas surrounding the observation wells. In addition, additional information on rise/fall in ground water round the year as indicated by observation wells and reasons of variation were discussed to identify chances of sustainability. The total investment made on project activities in village Gotoli from 2006 to 2012 was ₹ 38.78 lakh out of which 30.86% were spent on the construction of 15 earthen dams, 28.04% on land leveling and field bunding, 24.23% on plantation, 4.07% on crop improvement and 9.16% on the development of irrigation sources (Table1).

Soil moisture measurement from 0-180 cm depth were recorded from leveled land before and after the monsoon rains every year from three locations following gravimetric method to get the idea of movement of wetting front and its possible contribution for ground water recharge. The area of Gotoli village was divided into two micro-watersheds (MWS) having variable situation of recharge and extraction. A critical analysis of bio-physical conditions were attempted to develop a better understanding of sustainability of irrigation system. Some inferences were also drawn from another study village Gualda out of seven comprehensively evaluated. Few important lessons learnt from Gualda village study are also reported. The experiences of the farmers collected through household survey were appropriately incorporated in the study.

3. RESULTS AND DISCUSSION

Hydrological Potential for Ground Water Recharge

Rainfall was the only source for ground water recharge and its amount and distribution was important to determine the potential for recharge. The six years mean monsoon rainfall was 738 mm received in 36 rainfall events where the lowest was 538 and highest 1078mm received in 20 and 55 rainfall storms, respectively (Table 2).

The monsoon rainfall varied with high variability over space and time. The highest monthly rainfall of 359 mm was received in August 2010. On 11 September 2009, one day highest rainfall was 173 mm and on 3rd/4th September 2012, 228 mm of rainfall was received in one day. Occurrence of such occasional heavy storms and high runoff potential from barren and rocky *Aravalis* are the

Table: 1
Project investments (Thousand ₹) made on various components from 2006 to March 2012

S.No.	Particular	Years							Total	% of total
		2006	2007	2008	2009	2010	2011	2012		
1	Paals	184.96	536.03	65.26	198.06	212.80	0	0	1197.13	30.86
2	LL and FB	277.43	108.20	22.35	40.59	279.71	222.71	136.69	1087.70	28.04
3	Plantation	17.33	154.00	114.47	249.43	71.52	208.84	124.51	940.13	24.23
4	Crop demo	0	17.01	7.07	84.14	46.36	3.60	0	158.19	4.07
5	Tube-wells	272.43	82.91	0	0	0	0	0	355.34	9.16
6	Village dev.	0	0	0	0	0	0	140.27	140.27	3.61
	Total	752.15	898.15	209.15	572.22	610.39	435.15	401.47	3878.76	100%

Table: 2
Monthly rainfall in village Gotoli during different years (mm)

Year	2007	2008	2009	2010	2011	2012	Average
May	0	200	63	2	27	13	51
June	51	230	0	33	100	12	71
July	149	250	145	170	91	106	152
August	153	233	265	359	108	271	232
September	185	163	271	236	228	306	232
Total	538	1078	744	800	555	708	738
Events	20	55	22	39	38	40	36

two favourable hydrological features of the area for ground water recharge.

As such, the rainfall storms above 80 mm produced sufficient runoff for harvesting and contributed to reservoir storage and ground water recharge. Similar behavior of monsoon rains in the state of Rajasthan and potential for generating runoff and inducing recharge was also reported by Machiwal *et al*. (2013), John *et al*. (2009) and MoWR, 2009.

Construction of Earthen Dams for Rainwater Harvesting

In the period during 2006 and 2011, 15 earthen dams were constructed in village Gotoli at a total cost of ₹ 11.24 lakh which harvested rainwater from 884.89 ha of rocky *Aravali* hills and uneven and undulating lands below the hills with combined storage capacity of 52.98 ha-m (Table 3).

The problem with catchments forming private lands was that when these lands were gradually leveled and bunded (82.5 ha) under support from the project a major share of rainwater was conserved *in-situ* and did not contribute to reservoir storage and hence contribution to ground water recharge decreased. On the contrary, catchments forming part of common/community/forest land remained undisturbed and runoff reached the reservoirs. In case of Gotoli, 70% catchment area formed part of common land which continued to generate runoff. The *in-situ* conserved rain water proved very useful for Pearl millet crop but study of soil profile water storage indicated that this uniformly spread water on a level land did not reach the ground water. Moreover, on the reclaimed lands, new tube-wells were installed there by increasing the number of extracting units.

Analysis of Ground Water Extraction Units

The data collected from all the tube-well owners of village Gotoli revealed that between 1982 and 2012, the number of tube wells increased from just 2 to 128 (Fig. 1) and in the same period, the average water table decreased by 3.6 m.

The number of tube wells increased from 80 to 128 in six years of the project period. This increase coincided with the progressively increasing area of reclaimed land. Thus in a way, the land development activity proved counter productive in terms of increased ground water extraction.

As the water table went down, shallow tube wells had to be converted to submersible motors whose number increased from 7 to 71 from 2007 to 2012. But the number of diesel engines decreased from 43 to 14 (Fig. 2).

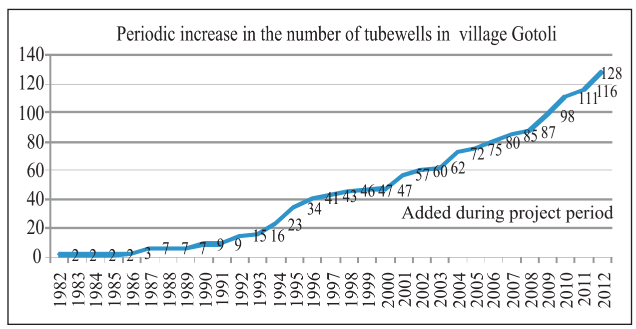

Fig.1. Number of tube wells installed by farmers in village Gotoli from 1982 to 2012

Table: 3
Detail of earthen dams constructed in village Gotoli

S.No.	Name of *Paal*	Year of Construction	Catchment Area (ha)	Land Ownership	Total Cost (Thousand ₹)	Storage capacity (ha-m)
1	Ram kishor wali	2006-07	8.5	Private	18.43	0.5
2	Leek wali	2006-07	38.5	Private	76.88	3.73
3	Kamal wali	2006-07	16.24	Private	62.43	1.68
4	Prakash wali	2006-07	4.0	Private	17.92	0.3
5	Esrail wali	2006-07	4.0	Private	19.96	1.0
6	Aaqup wali	2006-07	5.0	Private	46.38	0.3
7	Khati wali	2007-08	25.0	Private	98.40	2.23
8	Khadd wali	2007-08	210.0	Community	90.19	7.7
9	Cheekana teel	2007-08	357.0	Community	219.36	8.5
10	Dhundlee wali	2007-08	75.85	Private	131.67	17.31
11	Safeda wali	2007-08	9.8	Private	15.22	1.11
12	Balendi wali	2008-09	29.0	Private	37.32	3.12
13	Naya wali	2009-10	37.0	Private	49.02	1.5
14	Sharda wali	2009-10	10.0	Private	63.82	1.5
15	Jokha wali	2010-11	55.0	Community	177.26	2.5
	Total		884.89		1124.26	52.98

The need of submersible motors was felt during 2003-2004. The cost of conversion from diesel pump to submersible motor was ₹ 1.25 Lakh. So, there was an investment of ₹ 80 lakh on conversion of 64 (71-7) diesel engines to submersible motors due to lowering down of water table.

An area of 218.5 ha was irrigated during 2012 in this village. The data compiled from each tube well owner families and also our own data compiled from eight observation wells indicated that water table was falling at a rapidly varying from 0.6 to 0.9 m every year. This fall increased to 1.2 to 1.5 m in drought years. But because of recharge from monsoon rains particularly during high rainfall seasons, part of loss was recouped partially and the downward spiral continued.

Rain Water Harvested and Ground Water Recharge

Out of total 15 *Paals* constructed in village Gotoli, two representatives were selected for detailed monitoring by installing gauges. The results were extrapolated for the total *Paals* constructed in the village. The recharge varied according to the rainfall amount and distribution in different years. Over the last six years, the total groundwater recharge by all 15 *Paals* was 150.38 ha-m or 15038000 cu. m (Table 4).

Analysis of recharge data from individual storms indicated that heavy rainfall storms raised the level in the reservoirs and more the hydraulic head more was the rate of infiltration and percolation. Hence heavy rainfall storms contributed much more recharge than small storms. On 11 September 2009, one day highest rainfall was 173 mm and on 3rd/4th September 2012, 228 mm of rainfall was received in one day, so the ground water recharge was maximum in these two years in spite of overall rainfall being not very high (Table 4). The July and August rainfall was low in 2011 (Table 2), so it was not a good rainfall year for ground water recharge.

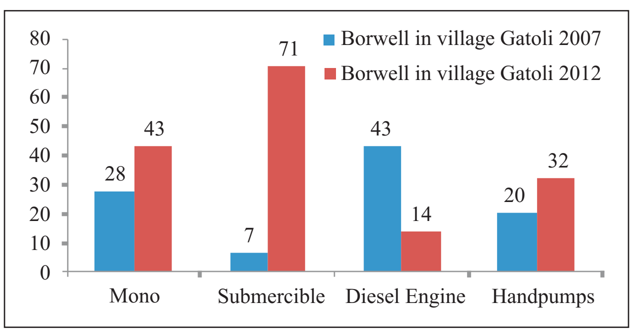

Fig. 2. Distribution of bore wells in village Gotoli

Trend of Groundwater Depletion

Three types of physiographic situations operated in the study village. The water levels varied between 14 to 16 m depth in lower elevations, 18 to 21 m in middle elevations and 24 to 26 m at relatively higher elevations. The main source of recharge was earthen dams and main source of depletion were bore wells. In some cases, motors were installed inside the observation wells for irrigation and in some wells water was extracted for human and livestock use either by tulu pumps or manually. Out of eight, only two typical observation wells one indicating the chances of sustainability and second indicating chances of non sustainability were selected to represent the trend of ground water depletion.

A Case of Un-sustainability indicated by Dargahwala observation Well

A maximum drop of 4.01 m was recorded between 30.6.2007 and 30.6.2013 in Dargahwala well (Fig. 3 and Table 5). There was rise of almost 4 m in water level during the monsoon of 2008 but also around 5.5 m drop in post monsoon season because of intensive irrigation. Again during the monsoon season of 2009, there was more than 4 m rise in ground water level and water level started rising during February and March, 2010 when good winter showers were received and irrigation was not needed. Then during 2011 and 2012, there was fewer rises during monsoon but more fall during post monsoon period indicating a clear declining trend. Evidently, due to runoff from nearby hills and there was good recharge during 2009 and 2010 but subsequently, as one motor for irrigation was installed in the well and four more submersible motors were installed nearby on reclaimed land and cropping pattern also changed to vegetable crops, the decline in water table started from 2011 onwards making the system unsustainable for irrigated agriculture.

A Case of Sustainability as Indicated by Basirwala Observation Well

This well presented a bit favourable situation though

Table: 4
Rainwater harvested and groundwater recharge from 2007 to 2012 in village Gotoli

Particulars	Ground water recharge in different years					
	2007	2008	2009	2010	2011	2012
No. of *Paals* in position	11	12	14	15	15	15
Rainfall (mm)	538	1078	744	800	555	708
Rain water harvested (ha-m)	15.6	32.2	39.83	22.12	1.64	45.65
Groundwater recharge (ha-m)	15.5	31.7	35.91	21.67	1.6	44.0
Cumulative groundwater recharge (ha-m)	15.5	47.20	83.11	104.78	106.38	150.38

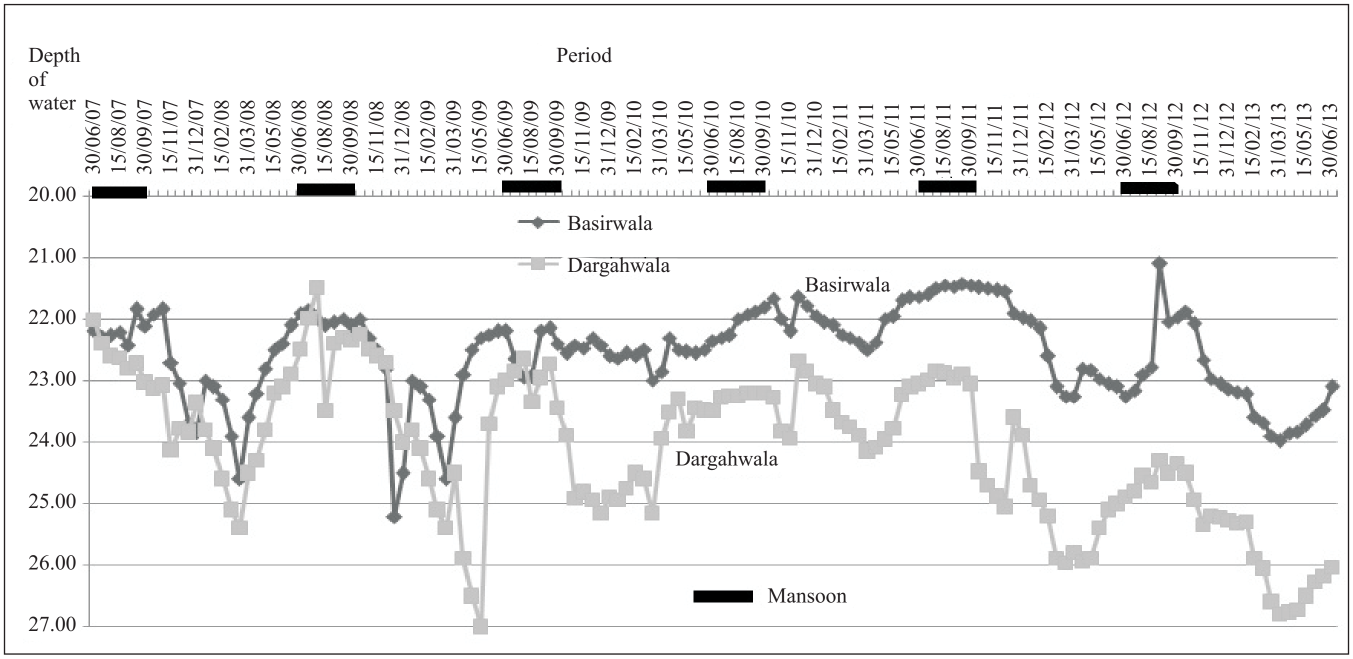

Fig. 3. Depth to water table on different dates in two bore wells showing slow (Basirwala) and faster (Dargahwala) depletion

Table: 5
Comparison of levels in observation wells before (30.06.07) and after (30.06.13) the project and ground water recharge and extraction conditions at village Gotoli

Name of wells	Groundwater levels (m)		Rise (+)/fall (-) in water table	Use of well water for		Recharge source*	Extracting source*	Remarks
	30.06.07	30.06.13		Irrigation	Drinking			
Basirwala	22.20	23.10	-0.90	7.5 hp motor	Not used	7 bigger *Paals* within 400 m radius	3 SM of 7.5 hp and 2 HP in a radius of 300 m	Sustainable, Green
Baniawala	20.17	22.17	-2.00	Not used	Not used	7 bigger *Paals* within 400 m	3 SM of 7.5 hp in a radius of 100 m	Partly Sustainable Yellow
Nayakuwa	15.96	18.01	-2.05	Not used	Not used	Big *Paal* upstream at distance of 250 m	3SM of 7.5 hp within a radius of 200 m	Unsustainable Red
Bagwala	19.18	21.02	-1.84	Not used	Tulu Pump for Livestock use	No *Paal* nearby	One 3 HP motor within a radius of 200 m	Partly Sustainable Yellow
Dargahwala	22.02	26.03	-4.01	5 hp pump	Not used	No *Paal* nearby	4 SM in a radius of 10 to100 m	Unsustainable Red
Bodiwala	21.29	23.90	-2.61	7.5 hp pump	Not used	No *Paal* nearby	3 SM and 1HP pump within a radius of 300 m	Unsustainable Red
Chaulaya	20.72	23.35	-2.63	Not used	4 Pumps of 0 hp	No *Paal* nearby	2 SM and 1 HP pump within a radius of 200 m	Unsustainable Red

*SM = Submersible motors; hp = horse power

0.90 m drop in groundwater level was recorded between 30.06.07 (before) and 30.06.13 (after). Like all other wells, the rise due to monsoon rains of 2007 was only 0.58 m as no *Paal* was constructed. The post monsoon drop up to March, 2008 was quite steep because of excessive withdrawal for *rabi* season crops. But after March, as crops were harvested, there was steep summer season rise. During 2008, in spite of good monsoon rainfall, there was not much rise because farmers in the surrounding area started raising summer onion (July to October season) which needed 12 to 15 irrigations to mature. This was followed by wheat which again needed six to seven irrigations triggering post monsoon season drop. But this drop was almost neutralized by winter rains and rest by summer season rise when crops were harvested. During 2009 again, the summer season rise was not recorded and post monsoon drop was not much. In 2010 monsoon again, instead of rise, drop was recorded mainly due to summer onion irrigations. But post monsoon drop was not that high. By 2011 monsoon end, the situation became quite favourable as seven *Paals* came up nearby. One 7.5 hp motor was installed in this well which caused steep drop during post monsoon period. But this drop was fully compensated by monsoon rains of 2012 and reached to peak rise because all *Paals* were full and started recharging the wells located downstream nearby. The extraction in post monsoon season of 2012-13 again dropped the level by almost 3 m. Seven *Paals* recharged and three motors nearby extracted ground water but water table started rising again in summer months when crops were harvested. At the end of the day, the situation appeared just manageable with net drop of 0.9 m against 4.01 m in Dhargahwala well.

Maximum fall in water table was recorded during peak period of withdrawal from December to February, when wheat, mustard and vegetable crops were irrigated. Astonishingly, there was rise in water table in summer months because there was no irrigation at that time. The drop was minimized when there were winter rains obliterating the need of irrigation.

Sustainability Analysis Based on Recharge and Extraction Pattern of Ground Water

There was no net rise in water table as indicated by seven observation wells between 30.06.2007 and 30.06.2013 but drop varied from 0.90 m to 4.01 m (Table 5).

It was noted that where observation well water was used for irrigation or drinking, there was no *Paal* in nearby area, number of submersible motors were installed on nearby reclaimed lands and cropping pattern changed in favour of vegetable crops, there was clear but variable drop in water table making the scenario as unsustainable for irrigated agriculture. Where there were number of *Paals* nearby, the drop was much less in spite of three submersible motors nearby showing chances of sustainability. Out of seven observation wells (Piezometer was not used for extraction of water), only one was near to sustainability, two were partly sustainable but remaining four were clearly unsustainable. The house hold survey indicated that most farmers had installed sprinkler sets because of saving in water and high subsidy on equipment. Almost all farmers used rubberized pipes for conveyance and hence water transmission losses were negligible.

Micro-watershed Based Analysis of Sustainability

In this analysis, it was noted that the larger size *Paals* were in A and smaller size in B MWS .The total area of MWS A and B were 674.05 and 156.20 ha, the number of *Paals* constructed 8 and 7, the storage capacity of *Paals* (76.0 and 18.95 ha-m), the ground water recharge (48.09 and 10.61 ha-m yr^{-1}), the number of tube wells near the observation wells (19 and 24) and area irrigated by these tube wells (58.12 and 78.27 ha), the water withdrawal by tube wells (72.58 and 91.68 ha-m yr^{-1}). The crop water requirement in case of A was less than B (Table 6).

The land use data indicated that area under onion and other vegetables was less in A as compared to B. Clearly, the area of MW B was more intensively cropped with less ground water recharge and hence the average net drop in groundwater level was 2.43 m. In MWS A, the recharge was more, number of tube wells were less and area under vegetable crop was less and due to the combined effect of these factors, average net drop was 0.85 m indicating chances of sustainability with demand management. In a similar study, Pande *et al*., 2015 concluded that the optimal extraction with desired change in cropping system and groundwater allocation is the panacea for falling groundwater table. Adhikari *et al.,* 2015 also reported the increase in area under irrigation during the post project period of a watershed development project leading to increased groundwater extraction.

Table: 6
Salient details of two micro-watersheds in four project villages

Particulars	MW A	MW B
Part A - Ground water recharge and irrigation details		
Total catchment area of micro-watershed (ha)	674.05	156.20
No. of Paals constructed in MW	8	7
Total storage capacity of Paals (ha-m)	76.0	18.95
Ground water recharge ha-m/year	48.09	10.61
No. of tube wells near observation wells	19	24
Area irrigated by tube wells ha	58.12	78.27
Water withdrawal by tube wells ha-m/year	72.58	91.68
Crop water requirement (ha-m)	23.25	27.16
Mean water table rise/fall in observation wells (mt)	-0.85	-2.43
Area under different crops (ha)		
Rabi - Wheat	28.0	32.5
Rabi - Mustard	21.0	36.5
Kharif - Cotton	0.5	1.5
Kharif - Onion	3.0	4.25
Kharif - Fodder	4.87	1.67
Kharif - Other vegetables	0.97	1.85
Total	58.12	78.27
Safety	Safe	Unsafe

In another study in village Gualda, the drop in ground water was 0.19 against 0.34 m yr^{-1} in Gotoli mainly because of two reasons. Firstly 40 earthen dams were constructed in this village since 2006 to harvest runoff water from the nearby hills (SPACE 2011). Secondly, it was noted that farmers retained almost 50% area under traditional Pearmillet and Mustard cropping sequence requiring only two to three irrigations and area under onion was restricted. So Gualda village was better place than Gotoli on the sustainability scale. An interesting observation on livelihood perspective is worth reporting. Most Gualda farmers were engaged in illegal mining activity providing them handsome returns and agriculture remained their secondary source of livelihood and hence less intensive cropping. However, farmers of Gotoli had no possibility of engaging in mining and resorted to intensive agriculture leading to more ground water extraction.

4. CONCLUSIONS

Occurrence of occasional heavy storms and high runoff potential from barren and rocky *Aravalis* were favourable hydrological features of the area for ground water recharge. However, 82.5 ha of wastelands were gradually leveled and bunded under support from the project conserved almost all the rainwater *in-situ* and curtailed inflow to the reservoirs and as a result contribution to ground water recharge decreased. Moreover, on the reclaimed lands, new tube-wells were installed thereby increasing the number of extracting units. So project promoted wasteland development proved counterproductive so far as ground water recharge was concerned.

It was noted that where observation well water was used for irrigation or drinking, there was no *Paal* in nearby area, number of submersible motors were installed on nearby reclaimed lands and cropping pattern changed in favour of vegetable crops, there was clear but variable drop in water table making the scenario as unsustainable for irrigated agriculture. Where there were number of *Paals* nearby, the drop was much less in spite of some submersible motors nearby showing chances of sustainability. Out of seven observation wells, only one turned out to be sustainable, two partly and remaining four fully unsustainable.

Clearly, when a micro-watershed area was more intensively cropped with less ground water recharge, the system turned out to be unsustainable with more drop in groundwater level. On the contrary, when recharge was more by large number of *Paals* and number of tube wells were limited and area under vegetable crop was less, the chances of sustainability were expected. Part of the area under traditional Bajra-Mustard cropping sequence requiring only two to three irrigations must be retained and area under January-May season onion should be replaced with area under August-October season onion to curtail demand on ground water recharge. Implementation of law on ground water extraction is also the need of the hour.

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